# Recent Scientific and Technical Books

*Volumes marked with an asterisk have been received at "NATURE" Office.*

## Mathematics

**Baker, H. F.** Principles of Geometry. Vol. 2: Plane Geometry, Conics, Circles, Non-Euclidean Geometry. Demy 8vo. Pp. xv+243. (Cambridge: At the University Press, 1922.) 15*s.* net.*

**Bruhns, Dr.,** Edited by. A New Manual of Logarithms to Seven Places of Decimals. Thirteenth stereotype edition. Sup. Roy. 8vo. Pp. xxiv+610. (London: Chapman and Hall, Ltd., 1922.) 12*s.* 6*d.* net.*

**Coventry, W. B.** The Racing Eight: Notes on its Design and Propulsion. Cr. 8vo. Pp. iv+39. (Cambridge: W. Heffer and Sons, Ltd.; London: Simpkin, Marshall and Co., Ltd., 1922.) 3*s.* 6*d.* net.*

**Goursat, E.** Leçons sur le problème de Pfaff. 8vo. Pp. viii+386. (Paris: J. Hermann, 1922.) 30 francs.

**Macgregor, D. C.** Mathematics and Physical Science in Classical Antiquity. Translated from the German of J. L. Heiberg. (Chapters in the History of Science, II.) Cr. 8vo. Pp. 110. (London: Oxford University Press, 1922.) 2*s.* 6*d.* net.*

**Moch, G.** Initiation aux théories d'Einstein. (Bibliothèque Larousse.) 8vo. Pp. 160. (Paris: Libr. Larousse, 1922.) 4 francs.

**Moreux, L'Abbé Th.** Pour comprendre la géométrie plane. Fcap. 8vo. Pp. 252. (Paris: G. Doin, 1922.) 8 francs.

**Neville, E. H.** Prolegomena to Analytical Geometry in Anisotropic Euclidean Space of Three Dimensions. Imp. 8vo. Pp. xxii+368. (Cambridge: At the University Press, 1922.) 30*s.* net.*

**Otzen, R.,** Herausgegeben von. Handbibliothek für Bauingenieure: Ein Hand- und Nachschlagebuch für Studium und Praxis. Teil I: Hilfswissenschaften. Erster Band: Mathematik. Von H. E. Timerding. 8vo. Pp. viii+242. (Berlin: J. Springer, 1923.)

**Shaw, J. B.** Vector Analysis: with Applications to Physics. Ex. Cr. 8vo. Pp. v+314. (London, Bombay and Sydney: Constable and Co., Ltd., 1922.) 14*s.* net.*

**Wulf, Le P. Th.** La Théorie de la relativité d'Einstein. Traduit par le P. H. Dopp. 8vo. Pp. 96. (Bruxelles: A. Dewett, 1922.) 2 francs.

## Mechanics: Mechanical Engineering

**Aeronautical Research Committee.** Reports and Memoranda: No. 541: Stability and Resistance Experiments on a Model of Vickers' Rigid Airship R.80. 6*d.* net. No. 769: The Calculation of Stresses in a Redundant Structure by the Method of Comparison of Deflections, with Examples of its Application to Aeroplane Design. 1*s.* 6*d.* net. No. 773: Lateral Control at large Angles of Incidence: Yawing and Rolling Moments due to Aileron Movement on a complete Model of S.E. 5a. 9*d.* net. No. 779: Experiments on a Model of Rigid Airship R.32, together with a Comparison with the Results of Full-Scale Turning Trials and a Consideration of the Stability of the Ship. 9*d.* net. No. 780: Aerodynamic Pressure on an Airship Hull in Curvilinear Flight. 6*d.* net. No. 781: The Motion of Airships under certain imposed Movements of the Rudders. 1*s.* 3*d.* net. No. 782: Equilibrium of R.38 in Circling Flight. 3*d.* net. No. 784: Seaplane: Taking Off and Alighting. 3*d.* net. No. 785: Experiments with Model Flying Boat Hulls and Seaplane Floats. 1*s.* net. No. 786: An Aerodynamic Theory of the Airscrew. 9*d.* net. No. 787: Lateral Control of Bristol Fighter at Low Speeds: Measurement of Rolling and Yawing Moments of Model Wings due to Rolling. 1*s.* 6*d.* net. No. 788: Theoretical Streamlines round a Joukowsky Aerofoil. 3*d.* net. No. 789: Preliminary Report on the Properties of commercially Pure Nickel as a Standard Material for Fatigue Investigations. 9*d.* net. No. 790: On the Determination of the Stresses in Braced Frameworks: Part 1, The Effect of Shear upon a Framework of Uniform Rectangular Cross-section. 6*d.* net. No. 791: On the Determination of the Stresses in Braced Frameworks: Part 2, The Effect of Axial Loading, Torsion, Flexure, and Shear upon a Braced Tube of any Uniform Cross-section. 6*d.* net. (London: H.M. Stationery Office, 1922.)

**Batson, R. G.,** and **Hyde, J. H.** Mechanical Testing: a Treatise in Two Volumes. Vol. 2: Testing of Prime Movers, Machines, Structures and Engineering Apparatus. (Directly-Useful Technical Series.) Demy 8vo. Pp. xi+446. (London: Chapman and Hall, Ltd., 1922.) 25*s.* net.*

**Bouasse, H.** Hydrostatique: Manomètres, baromètres, pompes: Équilibre des corps flottants. (Bibliothèque scientifique de l'Ingénieur et du Physicien.) 8vo. Pp. xxiv+480. (Paris: Libr. Delagrave, 1923.) 30 francs.

**Burley, G. W.** The Principles and Practice of Toothed Gear Wheel Cutting. 8vo. Pp. 468. (London: Scott, Greenwood and Son, 1922.) 25*s.* net.

**Cunningham, B.** A Treatise on the Principles and Practice of Dock Engineering. Third edition, revised and enlarged. Roy. 8vo. Pp. 618. (London: C. Griffin and Co., Ltd., 1922.) 42*s.* net.

**Hort, W.** Technische Schwingungslehre: Ein Handbuch für Ingenieure, Physiker und Mathematiker bei der Untersuchung der in der Technik angewendeten periodischen Vorgänge. Zweite, völlig umgearbeitete Auflage. (Berlin: J. Springer, 1922.)

**Kershaw, J. W.** Elementary Internal Combustion Engines. Second edition. Cr. 8vo. Pp. vii+212. (London: Longmans, Green and Co., 1922.) 5*s.* net.

**Manville, O.** Production économique de la vapeur. Roy. 8vo. Pp. vii+407. (Paris: G. Doin, 1923.) 25 francs.*

**Ministère de l'Agriculture**. Direction générale des Eaux et Forêts. (2e partie.) Service des grandes forces hydrauliques. (Région du Sud-Ouest.) Imp. 8vo. Tome 2 bis, Fascicule E: Résultats obtenus pour les bassins de l'Ariège et de l'Aude. Pp. iv+63 charts. Tome 7, Fascicule E-1: Résultats obtenus pour le bassin de l'Ariège pendant les années 1917 et 1918. Pp. 49+42 charts. Tome 7, Fascicule E-2: Résultats obtenus pour le bassin de l'Aude pendant les années 1917 et 1918. Pp. 26+10+26 charts. Tome 7, Fascicule F: Résultats obtenus pour les bassins de l'Agly, de la Têt, du Tech et du Sègre pendant les années 1917 et 1918. Pp. 73+72 charts. (Paris: Ministère de l'Agriculture, 1922.)*

**Motor-Cycles** and How to Manage Them. Twenty-third edition, revised and rewritten by the staff of the "Motor Cycle." Gl. 8vo. Pp. 292. (London: Iliffe and Sons, Ltd., 1922.) 2*s.* 6*d.* net.

**North, S. H.** Oil Power. (Pitman's Common Commodities and Industries.) Cr. 8vo. Pp. ix+122. (London: Sir I. Pitman and Sons, Ltd., 1922.) 3*s.* net.*

**Okill, J.** Internal-Combustion Engines: a Review of the Development and Construction of Various Types and their Economic Superiority for Modern Power Purposes. (Pitman's Common Commodities and Industries.) Cr. 8vo. Pp. xi+126. (London: Sir I. Pitman and Sons, Ltd., 1922.) 3*s.* net.*

**Orton, A.** The Diesel Engine: an Introductory Treatment of the Principles of Working, Construction, and Operation of Diesel Engines, for Students, Mechanics and Others. (Pitman's Technical Primers.) Fcap. 8vo. Pp. x+111. (London: Sir I. Pitman and Sons, Ltd., 1923.) 2*s.* 6*d.* net.*

**Ross, J. P.** Mechanical Engineering Detail Tables. Cr. 8vo. Pp. 209. (London: Sir I. Pitman and Sons, Ltd., 1922.) 7*s.* 6*d.* net.

**Wittenbauer, F.** Aufgaben aus der technischen Mechanik. Band III: Flüssigkeiten und Gase. Dritte, vermehrte und verbesserte Auflage. Pp. viii+390. (Berlin: J. Springer, 1923.)

## Physics: Electrical Engineering

**Bjerknes, V.** Untersuchungen über elektrische Resonanz. Sieben Abhandlungen aus den Jahren 1891–1895. Mit einer Einleitung dem Andenken an H. Hertz gewidmet. Pp. xxxii+129. (Leipzig: J. A. Barth, 1922.)

**Bohr, N.** The Theory of Spectra and Atomic Constitution: Three Essays. Demy 8vo. Pp. x+126. (Cambridge: At the University Press, 1922.) 7*s.* 6*d.* net.*

**Broglie, M. de.** Les Rayons X. (Recueil des conférences-rapports de documentation sur la physique. Vol. I., 1re Série, Conférences 1, 2, 3. Édité par la Société "Journal de Physique.") Roy. 8vo. Pp. 164+5 planches. (Paris: Les Presses universitaires de France, 1922.) 15 francs.*

**Collins, A. F.** The Radio Amateur's Hand-Book: a Complete Authentic and Informative Work on Wireless Telegraphy and Telephony. Cr. 8vo. Pp. xix+329+8 plates. (London, Calcutta and Sydney: G. G. Harrap and Co., Ltd., 1922.) 7*s.* 6*d.* net.*

**Department of Scientific and Industrial Research:** Fuel Research Board. Technical Paper No. 5: An Apparatus for the Measurement of Specific Gravity of Gases in Small Quantities. By A. Blackie. Roy. 8vo. Pp. ii+6+1 chart. (London: H.M. Stationery Office, 1922.) 3*d.* net.*

**Duroquier, F.** La Télégraphie sans fil des amateurs: Manuel pour la construction et l'utilisation des appareils récepteurs de télégraphie sans fil par ondes amorties et par ondes entretenues. 2e edition. 8vo. Pp. 303. (Paris: Masson et Cie, 1922.) 10 francs net.

**Hund, A.** Hochfrequenzmesstechnik: Ihre wissenschaftlichen und praktischen Grundlagen. (Berlin: J. Springer, 1922.)

**Johnson, V. E.** Electrical Recreations. 8vo. Pp. 160. (London: P. Marshall and Co., 1922.) 5*s.* net.

**Kohnstamm, P.** Lehrbuch der Thermodynamik in ihrer Anwendung auf das Gleichgewicht von Systemen mit gasförmigflüssigen Phasen. Nach Vorlesungen von J. D. van der Waals. Teil I. 2 verbesserte Auflage. Pp. xii+287. (Leipzig: J. A. Barth, 1923.)

**Mach, E.** Die Prinzipien der Wärmelehre: historisch-kritisch entwickelt. 4 Auflage. Pp. xiv+484. (Leipzig: J. A. Barth, 1923.)

**Michel, L.** Les Piles électriques. Fcap. 8vo. Pp. 135. (Paris: Gauthier-Villars et Cie, 1922.) 6 francs.

**Münzinger, F.** Ruths-Wärmespeicher in Kraftwerken. (Sonderabdruck aus den Mitteilungen Nr. 319 der Vereinigung der Elektrizitätswerke E. V.) 4to. Pp. 23. (Berlin: J. Springer, 1923.)

**Safeguarding of Industries Act.** Report of the Committee appointed to enquire into Complaint in respect of Optical Elements and Optical and other Scientific Instruments. (London: H.M. Stationery Office, 1922.) 9*d.* net.

**Vigneron, E.** Cours de mesures électriques professé à l'École spéciale des Travaux publics, du Bâtiment et de l'Industrie. Livre II: Essais de machines. Roy. 8vo. Pp. 613. (Paris: Librairie de l'Enseignement technique, 1922.)

**Williams, H. S.** Practical Radio. Cr. 8vo. Pp. 427. (London: Funk and Wagnalls Co., 1922.) 8*s.* 6*d.* net.

## Chemistry

**Arnold, K.** Abriss der allgemeinen Chemie (physikalischen oder theoretischen Chemie) zur Einführung in die neuzeitlichen Anschauungen der allgemeinen Chemie und zur Auskunft über die in derselben gebräuchlichen Ausdrücke. 3 neubearbeitete Auflage. Pp. viii+216. (Leipzig: L. Voss, 1923.)

**Bailey, G. H.,** and **Bausor, H. W.** Chemistry for Matriculation. Second edition. Cr. 8vo. Pp. viii+548. (London: University Tutorial Press, Ltd., 1922.) 8*s.* 6*d.*

**Blanchard, A. A.,** and **Phelan, J. W.** Synthetic Inorganic Chemistry. Third edition, entirely rewritten and greatly enlarged. Med. 8vo. Pp. 326. (New York: J. Wiley and Sons, Inc., 1922.) 3 dollars.

**Chapin, W. H.** Second Year College Chemistry. Med. 8vo. Pp. xi+311. (New York: J. Wiley and Sons, Inc.; London: Chapman and Hall, Ltd., 1922.) 15*s.* net.*

**Chapin, W. H.** Second Year College Chemistry: a Manual of Laboratory Exercises. Med. 8vo. Pp. vii+115. (New York: J. Wiley and Sons, Inc.; London: Chapman and Hall, Ltd., 1922.) 7*s.* 6*d.* net.*

**Clayton, W.** The Theory of Emulsions and Emulsification. (Text-Books of Chemical Research and Engineering.) Demy 8vo. Pp. viii+160. (London: J. and A. Churchill, 1923.) 9*s.* 6*d.* net.*

**Conant, J. B.,** Edited by. Organic Syntheses. Volume II of an Annual Publication of Satisfactory Methods for the Preparation of Organic Chemicals. Med. 8vo. Pp. 100. (New York: J. Wiley and Sons, Inc., 1922.) 1.50 dollars.

**Eucken, A.** Grundriss der physikalischen Chemie. 8vo. Pp. viii+492. (Leipzig: Akademische Verlagsgesellschaft, 1922.) 220 marks.

**Folin, O.** Laboratory Manual of Biological Chemistry. With Supplement. New edition. Med. 8vo. Pp. 301. (London: D. Appleton and Co., 1922.) 12*s.* 6*d.* net.

**Franke, A.** Leitfaden für die chemischen Übungen der Studierenden der Medizin. 2 Auflage. Pp. 62. (Leipzig und Wien: F. Deuticke, 1922.)

**Kamm, O.** Qualitative Organic Analysis. Med. 8vo. Pp. 245. (New York: J. Wiley and Sons, Inc., 1922.)

**Kratz, A. P.,** and **Rosecrans, C. Z.** A Study of Explosions of Gaseous Mixtures. (Engineering Experiment Station Bulletin No. 133.) Med. 8vo. Pp. 104. (Urbana, Ill.: University of Illinois, 1922.) 55 cents.*

**Lassar-Cohn.** Arbeitsmethoden für organisch-chemische Laboratorien. 5 umgeänderte und verbesserte Auflage. Spezieller Teil. 1 Hälfte. Pp. 640. (Leipzig: L. Voss, 1923.)

**Michaelis, L.** Praktikum der physikalischen Chemie, insbesondere der Kolloidchemie für Mediziner und Biologen. Zweite, verbesserte Auflage. 8vo. Pp. viii+183. (Berlin: J. Springer, 1923.)

**Mulliken, S. P.** Identification of Pure Organic Compounds. Volume IV: Containing Classified Descriptions of about 3700 of the more important Compounds belonging to Fourteen of the Higher Orders. Sup. Roy. 8vo. Pp. 238. (New York: J. Wiley and Sons, Inc., 1922.) 6 dollars.

**Ostwald, W.** Einführung in die Chemie: Ein Lehrbuch zum Selbstunterricht und für höhere Lehranstalten. 3 Auflage. Pp. 238. (Stuttgart: Dieck und Co., 1922.)

**Sinnatt, F. S.** The Inorganic Constituents of Coal. Part III: The Chemical Composition of Iron Pyrites from Coal. (Lancashire and Cheshire Coal Research Association Bulletin, No. 12.) Cr. 8vo. (London: H. F. and G. Witherby, 1922.) 2*s.* net.

**Smith's** Intermediate Chemistry. Revised and rewritten by J. Kendall and E. E. Slosson. Ex. Cr. 8vo. Pp. xv+566. (New York: The Century Co.; London: G. Bell and Sons, Ltd., 1922.) 8*s.* 6*d.* net.*

**Union Internationale de la Chimie.** Tables annuelles de constantes et données numériques de chimie, de physique et de technologie. Vol. IV: Années 1913–1914–1915–1916. Demy 4to. Première partie. Pp. xxxii+626. Deuxième partie. Pp. xxxv+627-1377. (Paris: Gauthier-Villars et Cie; London: Cambridge University Press; Chicago: University of Chicago Press, 1921–1922.) 2 parts, 140*s.**

**Vita-Massenez.** Chemische Untersuchungsmethoden für Eisenhütten und Nebenbetriebe: Eine Sammlung praktisch erprobter Arbeitsverfahren. Zweite, neubearbeitete Auflage. (Berlin: J. Springer, 1922.)

## Technology

**Auden, H. A.** Starch and Starch Products. (Pitman's Common Commodities and Industries.) Cr. 8vo. Pp. 134. (London: Sir I. Pitman and Sons, Ltd., 1922.) 3*s.* net.

**Cescinsky, H.,** and **Gribble, E. R.** Early English Furniture and Woodwork. In two volumes. Sup. Roy. 4to. Vol. I. Pp. xvi+382. Vol. II. Pp. vii+387. (London: G. Routledge and Sons, Ltd., 1922.) 147*s.* net.

**Dubbel, H.** Taschenbuch für den Fabrikbetrieb. Bearbeitet von O. Brandt, H. Dubbel, W. Franz, R. Hänchen, O. Heinrich, O. Kienzle, R. Kühnel, H. Lux, K. Meller, W. Mitan, W. Quack, E. Sachsenberg, H. R. Trenkler. 8vo. Pp. vii+980+8 Tafeln. (Berlin: J. Springer, 1923.)

**Fourquet, J.,** et **Lemesle, O.** L'Apprenti-menuisier. Pp. 330. (Paris: L. Eyrolles, 1922.) 8 francs.

**Gibson, C. R.** The Romance of Coal. Cr. 8vo. Pp. 310. (London: Seeley Service and Co., Ltd., 1922.) 6*s.* net.

**Inwards, H.** Straw Hats: Their History and Manufacture. (Pitman's Common Commodities and Industries.) Cr. 8vo. Pp. xi+126. (London: Sir I. Pitman and Sons, Ltd., 1922.) 3*s.* net.

**Jourdain, M.** English Decoration and Furniture of the Later XVIIIth Century (1750–1820): an Account of its Development and Characteristic Forms. (Library of Decorative Art.) Imp. 4to. Pp. xvi+269. (London: B. T. Batsford, Ltd., 1922.) 63*s.* net.

**Kind, W.** Das Bleichen der Pflanzenfasern. Zweite, vermehrte und verbesserte Auflage. Pp. 372. (Wittenberg: A. Ziemsen, 1922.)

**Krause, H.** Metallfärbung: Die wichtigsten Verfahren zur Oberflächenfärbung von Metallgegenständen. (Berlin: J. Springer, 1922.)

**Mitchell, O.** The Talking Machine Industry. (Pitman's Common Commodities and Industries.) Cr. 8vo. Pp. xiv+120. (London: Sir I. Pitman and Sons, Ltd., 1922.) 3*s.* net.*

**Sauer, K.** Leitfaden der Hüttenkunde für Maschinentechniker. Zweite, durchgesehene Auflage. 8vo. Pp. iv+90. (Berlin: J. Springer, 1923.)

**Simon, E.,** Herausgegeben von. Werkstattbücher für Betriebsbeamte, Vor- und Facharbeiter. Heft 11. Freiformschmiede I: Technologie der Schmiede—Rohstoffe der Schmiede. Von P. H. Schweissguth. 8vo. Pp. ii+72. (Berlin: J. Springer, 1923.)

**Sinnatt, F. S.** The Stone Dusting of Mines. Part II. (Lancashire and Cheshire Coal Research Association Bulletin, No. 11.) Cr. 8vo. (London: H. F. and G. Witherby, 1922.) 2*s.* net.

**Tipping, H. A.** English Furniture of the Cabriole Period. 4to. Pp. viii+79+32 plates. (London: Jonathan Cape, 1922.) 12*s.* 6*d.* net.

**Townsend, W. G. P.** Modern Decorative Art in England: its Development and Characteristics. Vol. 1: Woven and Printed Fabrics, Wall-papers, Lace, and Embroidery. Sup. Roy. 4to. Pp. 164. (London: B. T. Batsford, Ltd., 1922.) 25*s.* net.

**Vesper, C.** Batik. Anleitung zur Herstellung gebatikter Gewebe und Stoffe, wie Baumwolle, Leinen, Nessel, Seide, Samt, Leder, Pergament, Papier, Holz, Korbweiden, Metall, Glas, Elfenbein, Linoleum. Mit Anhang: Bandana-Druckverfahren, Bemalen der Stoffe, Wasch- und lichtechte Handmalerei, Spritzverfahren. Pp. 64. (Wittenberg: A. Ziemsen, 1922.)

**Zart, A.** Die Entwicklung der chemischen Grossindustrie. (Der Werdegang der Entdeckungen und Erfindungen, Heft 5.) Pp. 48. (München und Berlin: R. Oldenbourg, 1922.)

## Astronomy

**Bigelow, F. H.** Supplement No. 4 to the Treatises on the Atmospheres of the Sun and the Earth: Atmospheric Radiation, Electricity and Magnetism. Med. 8vo. Pp. viii+89. (Printed in Vienna, 1922.) *

**Mang, A.** Die Volkssternwarte. 8vo. Pp. 16. (Stuttgart: A. Mang, 1922.) 10 marks.

**Poor, C. L.** Gravitation versus Relativity: a Non-Technical Explanation of the Fundamental Principles of Gravitational Astronomy and a Critical Examination of the Astronomical Evidence cited as Proof of the Generalized Theory of Relativity. Post 8vo. Pp. xxxiv+277. (London: G. P. Putnam's Sons, Ltd., 1922.) 12*s.* 6*d.* net.

**Schiller, K.** Einführung in das Studium der veränderlichen Sterne. Pp. viii+384. (Leipzig: J. A. Barth, 1923.)

## Meteorology

**Braak, C.** On Cloud-Formation: Nuclei of Condensation, Haziness, Dimensions of Cloud Particles. (Koninklijk Magnetisch en Meteorologisch Observatorium te Batavia. Verhandelingen No. 10.) Imp. 8vo. Pp. ii+33. (Batavia: Javasche Boekhandel en Drukkerij, 1922.) *

**Manson, M.** The Evolution of Climates. 8vo. Pp. 66. (Baltimore, Md.: The Lord Baltimore Press, 1922.)

**Meteorological Office: Air Ministry.** British Rainfall, 1921. The Sixty-first Annual Volume of the British Rainfall Organization. Report on the Distribution of Rain in Space and Time over the British Isles during the Year 1921, as recorded by more than 5000 Observers in Great Britain and Ireland. Demy 8vo. Pp. xxiv+300. (London: H.M. Stationery Office, 1922.) 12*s.* 6*d.* net.*

## Geology: Mineralogy

**Breitensteins Repetitorien.** Nr. 45: Geologie. 1: Allgemeine Geologie. 2 Auflage. Pp. 112. (Leipzig: J. A. Barth, 1922.) 2*s.*

**Cloos, H.** Tektonik und Magma: Untersuchungen zur Geologie der Tiefen. Band I. 8vo. Pp. 142. (Berlin: Preussische Geologische Landesanstalt, 1922.) 36 marks.

**Cole, G. A. J.** Memoir and Map of Localities of Minerals of Economic Importance and Metalliferous Mines in Ireland. (Department of Agriculture and Technical Instruction for Ireland. Memoirs of the Geological Survey of Ireland: Mineral Resources.) Roy. 8vo. Pp. 155. (Dublin: Stationery Office, 1922.) 7*s.* 6*d.* net.*

**Collins, W. F.** Mineral Enterprise in China. Second edition, revised. 8vo. Pp. 425. (London: Probsthain and Co., 1922.) 32*s.* net.

**Department of Scientific and Industrial Research:** Memoirs of the Geological Survey. Summary of Progress of the Geological Survey of Great Britain and the Museum of Practical Geology for 1921, with Report of the Geological Survey Board and Report of the Director. Roy. 8vo. Pp. iv+189. (Southampton: Ordnance Survey Office; London: E. Stanford, Ltd., 1922.) 5*s.* net.*

**Fallot, P.** Étude géologique de la Sierra de Majorque. 4to. Pp. viii+482+18 planches. (Paris et Liége: Ch. Béranger, 1922.)

**Febvre, L.,** et **Bataillon, L.** La Terre et l'évolution humaine: Introduction géographique à l'histoire. (Bibliothèque de Synthèse historique: L'Évolution de l'Humanité.) 8vo. Pp. xxvi+472. (Paris: La Renaissance du Livre, 1922.)

**Huene, F. von.** Die Ichthyosaurier des Lias und ihre Zusammenhänge. Sup. Roy. 4to. Pp. viii+114+22 Tafeln. (Berlin: Gebrüder Borntraeger, 1922.) 25*s.**

**Imperial Mineral Resources Bureau.** Mineral Industry of the British Empire and Foreign Countries, War period. Iron Ore, part 7: Foreign America. 4*s.* net. Iron Ore, part 8: Foreign Asia. 2*s.* 6*d.* net. Nickel. 1*s.* 6*d.* net. Vanadium. 6*d.* net. (London: H.M. Stationery Office, 1922.)

**Krenkel, E.** Die Bruchzonen Ostafrikas: Tektonik, Vulkanismus, Erdbeben und Schwereanomalien. Roy. 8vo. Pp. viii+184. (Berlin: Gebrüder Borntraeger, 1922.) 7*s.* 4*d.**

**Lucas, F. A.** Animals of the Past: an Account of some of the Creatures of the Ancient World. (Handbook Series, No. 4.) Sixth and revised edition. Ex. Cr. 8vo. Pp. xii+207. (New York: American Museum of Natural History, 1922.) *

**Rastall, R. H.** Molybdenum Ores. (Imperial Institute: Monographs on Mineral Resources, with Special Reference to the British Empire.) Demy 8vo. Pp. ix+86. (London: J. Murray, 1922.) 5*s.* net.*

**Stoek, H. H., Fleming, J. R.,** and **Hoskin, A. J.** A Study of Coal Mine Haulage in Illinois. (Engineering Experiment Station Bulletin No. 132.) Med. 8vo. Pp. 136. (Urbana, Ill.: University of Illinois, 1922.) *

**Visser, S. W.** Inland and Submarine Epicentra of Sumatra and Java Earthquakes. (Koninklijk Magnetisch en Meteorologisch Observatorium te Batavia. Verhandelingen No. 9: Complement to Verhandelingen No. 7.) Imp. 8vo. Pp. ii+14. (Batavia: Javasche Boekhandel en Drukkerij, 1922.) *

**Wagner, P. A.** The Pretoria Salt-Pan: a Soda Caldera. (Department of Mines and Industries: Geological Survey, Memoir No. 20.) Roy. 8vo. Pp. 136+19 plates. (Pretoria: Government Printing and Stationery Office, 1922.) 7*s.* 6*d.**

**Winchell, A. N.** Elements of Optical Mineralogy. Part 1: Principles and Methods. Second edition, entirely rewritten and much enlarged. Med. 8vo. Pp. 216. (New York: J. Wiley and Sons, Inc., 1922.) 2.50 dollars.

## Geography: Travel

**Beard, C. A.,** and **Bagley, W. C.** Our Old World Background. Large Cr. 8vo. Pp. xi+504. (New York: The Macmillan Co.; London: Macmillan and Co., Ltd., 1922.) 6*s.* net.

**Blunden, E.** The Bonadventure: a Random Journal of an Atlantic Holiday. Cr. 8vo. Pp. 192. (London: R. Cobden-Sanderson, 1922.) 6*s.* net.

**Bosworth, G. F.** Essex. Pocket edition. Cr. 8vo. Pp. 175. (Cambridge: At the University Press, 1922.) 4*s.* 6*d.* net.

**Bosworth, G. F.** Kent. Pocket edition. Cr. 8vo. Pp. 154. (Cambridge: At the University Press, 1922.) 4*s.* 6*d.* net.

**Bosworth, G. F.** Surrey. Pocket edition. Cr. 8vo. Pp. 159. (Cambridge: At the University Press, 1922.) 4*s.* 6*d.* net.

**Bosworth, G. F.** Sussex. Pocket edition. Cr. 8vo. Pp. 152. (Cambridge: At the University Press, 1922.) 4*s.* 6*d.* net.

**Chamberlain, I.** and **H.** Common Objects of the Riviera. Cheaper edition. Cr. 8vo. Pp. 207. (London: G. Routledge and Sons, Ltd., 1922.) 3*s.* 6*d.* net.

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**Guillain, G.** Études neurologiques. Med. 8vo. Pp. viii+470+4 planches. (Paris: Masson et Cie, 1922.) 25 francs net.

**Guillaume, A.-C.** Les Occlusions aiguës et subaiguës de l'intestin: Clinique, expérimentation, thérapeutique. Pp. 304. (Paris: Masson et Cie, 1922.) 12 francs net.

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**Hadfield, C. F.** Practical Anæsthetics for the Student and General Practitioner. Demy 8vo. Pp. xii+244. (London: Baillière, Tindall and Cox, 1922.) 7*s.* 6*d.* net.

**Hirsch, M.,** Herausgegeben von. Monographien zur Frauenkunde und Eugenetik, Sexualbiologie und Vererbungslehre. Nr. 5: Schmerz und Geschlechtstrieb. Versuch einer Analyse und Theorie der Algolagnie. (Sadismus und Masochismus.) Von J. Schuster. Pp. iv+43. (Leipzig: C. Kabitzsch, 1923.)

**Jarricot, J.** Le Dispensaire marin: Un organisme nouveau de puériculture. Roy. 8vo. Pp. 628+54 planches. (Paris: Masson et Cie, 1922.) 60 francs net.

**Jessner, S.** Dermatologische Heilmittel (Pharmacopœa dermatologica). (Dermatologische Vorträge für Praktiker, Heft 8.) 4 Auflage. Pp. 91. (Leipzig: C. Kabitzsch, 1923.)

**Jessner, S.** Lehrbuch der Haut- und Geschlechtsleiden einschliesslich der Syphilide und einer kurzen Kosmetik, für Studierende und Ärzte. 6-7 umgearbeitete und sehr erweiterte Auflage. Band 1: Hautleiden und Kosmetik. Pp. xvii+497+39 Tafeln. (Leipzig: C. Kabitzsch, 1923.)

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**Juppé, F.** L'Apothicairerie en Béarn. 8vo. Pp. 157. (Tarbes: Libr. Desbordes, 1922.)

**Labat, G.** Regional Anesthesia. 8vo. Pp. 496. (Philadelphia and London: W. B. Saunders Co., Ltd., 1922.) 35*s.* net.

**Laqueur, A.** Die Praxis der physikalischen Therapie. Zweite Auflage. Pp. 360. (Berlin: J. Springer, 1922.) 384 marks.

**Lematte, L.** L'Opothérapie du praticien. Fcap. 8vo. Pp. 238+3 planches. (Paris: A. Maloine et fils, 1923.) 5 francs.

**McCoy, J. D.** Dental and Oral Radiography: a Textbook for Students and Practitioners of Dentistry. Third edition. Roy. 8vo. Pp. 197. (London: H. Kimpton, 1922.) 15*s.* net.

**Madinier, J.** La Thoracoplastie extra-pleurale dans le traitement de la tuberculose pulmonaire. Pp. 124. (Paris: Masson et Cie, 1922.) 12 francs.

**Marie, P.** Questions neurologiques d'actualité. 20 Conférences faites à la Faculté de Médecine de Paris en 1921. Roy. 8vo. Pp. 552. (Paris: Masson et Cie, 1922.) 28 francs net.

**Martinet, A.,** avec la collaboration des Drs. Desfosses, G. Laurens, L. Meunier, Lutier, Saint-Cène et Terson. Diagnostic clinique: Examens et symptômes. 4e édition revue et complétée. Pp. 1040. (Paris: Masson et Cie, 1922.) 55 francs.

**Medical Officers of Schools Association.** A Code of Rules for the Prevention of Infectious and Contagious Diseases in Schools. Eighth edition. 8vo. Pp. 48. (London: J. and A. Churchill, 1922.) 2*s.* 6*d.* net.

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**Proust, R.,** et **Charrier, J.** Chirurgie de l'appareil génital de la femme. Nouvelle série. Pp. 300. (Paris: Masson et Cie, 1922.) 10 francs.

**Rabinowitsch, L.,** Herausgegeben von. Tuberkulose-Bibliothek. Nr. 9: Der klinische Betrieb in den Lungenheilanstalten. Von G. Liebe. Pp. 25. (Leipzig: J. A. Barth, 1922.)

**Ravaut, P.** Syphilis, paludisme, amibiase: le Traitement d'attaque et les traitements secondaires (préventif, abortif et d'entretien). 2e édition refondue. Pp. 214. (Paris: Masson et Cie, 1922.) 9 francs.

**Reinheimer, H.** Symbiosis *v.* Cancer. Gl. 8vo. Pp. 99. (London: Headley Bros., 1922.) 5*s.**

**Roger, G.-H., Widal, F.,** et **Teissier, P.-J.** Nouveau Traité de médecine. Fasc. 2: Maladies infectieuses (suite). Pp. 765+8 planches. Fasc. 5: Maladies infectieuses et parasitaires (fin), cancer. Pp. 740+4 planches. (Paris: Masson et Cie, 1922.) 50 francs each.

**Rose, W. D.** Physical Diagnosis. Third edition, revised and enlarged. Roy. 8vo. Pp. 755. (London: H. Kimpton, 1923.) 45*s.* net.

**Schnirer, M. T.** Taschenbuch der Therapie mit besonderer Berücksichtigung der Therapie an den Berliner, Wiener und an deutschen Kliniken. Neunzehnte Ausgabe. Small 8vo. Pp. xvi+472. (Leipzig: C. Kabitzsch, 1923.)

**Schwalbe, J.,** Herausgegeben von. Diagnostische und therapeutische Irrtümer und deren Verhütung. Vierzehntes Heft: Erkrankungen der oberen Luftwege. Von Dr. Friedrich und Dr. Albanus. Pp. 86. (Leipzig: G. Thieme, 1922.) 3*s.* 4*d.*

**Sergent, E., Ribadeau-Dumas, L.,** et **Babonneix, L.,** Édité par. Traité de pathologie médicale et de thérapeutique appliquée. Appareil respiratoire. Tome I. Pp. 395. (Paris: A. Maloine et fils, 1922.) 20 francs.

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**Sopp, A.** Ärztliche Beratung zur Ergänzung der Sprechstunde. Nr. 11: Die Erkrankungen der Leber und Gallenblase, insbesondere der Gelbsucht und Gallensteinkrankheit. Pp. iv + 56. (Leipzig: C. Kabitzsch, 1923.)

**Sudhoff, K.,** Herausgegeben von. Klassiker der Medizin. Band 28: Hippokrates. Der Volkskrankheiten erstes und drittes Buch (um das Jahr 434-430 vor Christus). Aus dem Griechischen übersetzt und erläutert von G. Sticker. Pp. 135. Band 29: Ambroise Paré, Die Behandlung der Schusswunden (1545). Eingeleitet, übersetzt und herausgegeben von H. E. Sigerist. Pp. 87. (Leipzig: J. A. Barth, 1923.)

**Sudhoff, K.,** Herausgegeben von. Studien zur Geschichte der Medizin. Heft 13: Studien und Texte zur frühmittelalterlichen Rezeptliteratur. Von H. E. Sigerist. Pp. viii + 220. (Leipzig: J. A. Barth, 1923.)

**Thierry, de Martel,** et **Antoine, E.** Les Fausses Appendicites: Étude clinique, radiologique et thérapeutique. Pp. 184 + 10 planches. (Paris: Masson et Cie, 1922.) 10 francs net.

**Timbal, L.** Les Diarrhées chroniques: Étude clinique, coprologique et thérapeutique. Pp. 270. (Paris: Masson et Cie, 1922.) 12 francs net.

**Traugott, R.** Die nervöse Schlaflosigkeit und ihre Behandlung. Vierte gänzlich umgearbeitete Auflage. 8vo. Pp. vi + 116. (Leipzig: C. Kabitzsch, 1923.)

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**Whitla, Sir W.** Elements of Pharmacy, Materia Medica, and Therapeutics. Eleventh edition. Cr. 8vo. Pp. x + 680. (London: Baillière, Tindall and Cox, 1922.) 10*s.* 6*d.* net.

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## Miscellaneous

**Adult Education Committee.** The Development of Adult Education in Rural Areas. (Paper No. 3.) Gl. 8vo. Pp. vi + 55. (London: H.M. Stationery Office, 1922.) 6*d.* net.*

**Antiquity.** The Claim of Antiquity, with an Annotated List of Books for those who know neither Latin nor Greek. (Issued by the Councils of the Societies for the Promotion of Hellenic and Roman Studies and of the Classical Association.) Cr. 8vo. Pp. 30. (London: Oxford University Press, 1922.) 1*s.**

**Ashley, Sir W.** Scientific Management and the Engineering Situation: Sidney Ball Memorial Lecture delivered before the University of Oxford, October 28, 1922. (Barnett House Papers, No. 7.) Demy 8vo. Pp. 28. (London: Oxford University Press, 1922.) 1*s.**

**Brown, G. E.,** Edited by. The British Journal Photographic Almanac and Photographer's Daily Companion, 1923. Sixty-second Issue. Cr. 8vo. Pp. 808. (London: H. Greenwood and Co., Ltd., 1923.) Paper, 2*s.* net; Cloth, 3*s.* net.*

**Cressy, E.** Discoveries and Inventions of the Twentieth Century. Second edition, revised and enlarged. Demy 8vo. Pp. xxiii + 458 + plates. (London: G. Routledge and Sons, Ltd.; New York: E. P. Dutton and Co., 1923.) 12*s.* 6*d.* net.*

**Department of the Interior: Bureau of Education.** Statistics of City School Systems, 1919–20. Prepared by the Statistical Division of the Bureau of Education under the Direction of H. R. Bonner. (Bulletin No. 17.) Med. 8vo. Pp. 173. (Washington: Government Printing Office, 1922.) 20 cents.*

**Department of the Interior: Bureau of Education.** Statistics of Universities, Colleges, and Professional Schools, 1919–1920. (Bulletin No. 28.) Med. 8vo. Pp. 147. (Washington: Government Printing Office, 1922.) 15 cents.*

**Department of the Interior: Bureau of Education.** Accredited Secondary Schools in the United States. (Bulletin No. 11.) Med. 8vo. Pp. 96. (Washington: Government Printing Office, 1922.) 10 cents.*

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**Evans, R. C. T.** Man: What? Whence? Whither? or the Faith that is in Me. Demy 8vo. Pp. v + 146. (Chatham: Parrett and Neves, Ltd., 1922.) 2*s.* net.*

**Gamble, W.,** Edited by. Penrose's Annual: The Process Year Book. Review of the Graphic Arts, 1923. Vol. 25. Cr. 4to. Pp. xvi + 110 + plates + 64. (London: P. Lund, Humphries and Co., Ltd., 1923.) 8*s.* net.*

**Hanffstengel, G. von.** Die Förderung von Massengütern. Band I: Bau und Berechnung der stetig arbeitenden Förderer. Dritte, umgearbeitete und vermehrte Auflage. 8vo. Pp. viii + 306. (Berlin: J. Springer, 1923.)

**Klages, L.** Handschrift und Charakter: Gemeinverständlicher Abriss der graphologischen Technik. 5 bis 7 Auflage. Pp. xii + 254. (Leipzig: J. A. Barth, 1923.)

**Mellish, M. H.** The Writing of Medical Papers. 12mo. Pp. 157. (Philadelphia and London: W. B. Saunders Co., Ltd., 1922.) 7*s.* 6*d.* net.

**Mortimer, F. J.,** Edited by. Photograms of the Year 1922: the Annual Review for 1923 of the World's Pictorial Photographic Work. Demy 4to. Pp. 34 + 64 plates. (London: Iliffe and Sons, Ltd., 1922.) 6*s.* net.

**Moulton, H. F.** The Life of Lord Moulton. Demy 8vo. Pp. 287 + 8 plates. (London: Nisbet and Co., Ltd., 1922.) 15*s.* net.*

**Olivier, E.,** und **Sigismund, R.** Französisch für Mediziner. 4 Auflage. Pp. viii + 168. (Leipzig: J. A. Barth, 1922.) 4*s.*

**Pearson, F. R.** Problems in Intermediate Science: Physics, Heat, Chemistry. Third edition. Cr. 8vo. Pp. 80. (Edinburgh: Oliver and Boyd; London: Gurney and Jackson, 1922.) 2*s.* 6*d.* net.

**Robertson, A.** The Life of Sir Robert Moray: Soldier Statesman and Man of Science (1608–1673). Demy 8vo. Pp. xiii + 223. (London: Longmans, Green and Co., 1922.) 12*s.* 6*d.* net.*

**Schuster, J.** Oken: der Mann und sein Werk. Vortrag auf der Jahrhundert-Tagung der Gesellschaft Deutscher Naturforscher und Ärzte zu Leipzig. Cr. 4to. Pp. 24. (Berlin: W. Junk, 1922.)*

**Scientific and Learned Societies of Great Britain and Ireland,** The Year-Book of the. A Record of the Work done in Science, Literature, and Art during the Session 1921–22, by numerous Societies and Government Institutions. Compiled from Official Sources. Thirty-ninth Annual Issue. Demy 8vo. Pp. vii + 374. (London: C. Griffin and Co., Ltd., 1922.) 15*s.* net.*

**Siemens, W. von.** Lebenserinnerungen. Zwölfte Auflage. Pp. iv + 221 + 6 Tafeln. (Berlin: J. Springer, 1923.)

**Venn, J.,** and **Venn, J. A.,** Compiled by. Alumni Cantabrigienses: a Biographical List of all known Students, Graduates and Holders of Office at the University of Cambridge, from the Earliest Times to 1900. Part 1: From the Earliest Times to 1751. Vol. 2: Dabbs-Juxton. Cr. 4to. Pp. v + 492. (Cambridge: At the University Press, 1922.) 150*s.* net.*

**Washburne, C. W.** Common Science. Cr. 8vo. Pp. xv + 390. (London: G. Bell and Sons, Ltd., 1923.) 4*s.* 6*d.**

# Recent Scientific and Technical Books

*Volumes marked with an asterisk have been received at "NATURE" Office.*

## Mathematics

**Andoyer, H.** Tables logarithmiques à treize décimales. Imp. 8vo. Pp. x+27. (Paris: J. Hermann, 1922.) 8 francs.*

**Boutroux, P.** Les Mathématiques. (Bibliothèque "Cosmos.") Fcap. 8vo. Pp. 184. (Paris: A. Michel, 1922.) 5 francs.

**Clapham, C. B.** Arithmetic for Engineers: including Simple Algebra, Mensuration, Logarithms, Graphs, Trigonometry, and the Slide Rule; with an Appendix on Verniers and Micrometers. (The Directly-Useful Technical Series.) Demy 8vo. Pp. xiii+491. (London: Chapman and Hall, Ltd., 1922.) 7*s.* 6*d.* net.*

**Cosens, C. R. G.,** Compiled by. Two-figure Tables. On card 10″ × 4½″. (Cambridge: Bowes and Bowes; London: Macmillan and Co., Ltd., 1923.) 6*d.**

**Cunningham, A., Woodall, H. J.,** and **Creak, T. G.** Haupt-Exponents, Residue Indices, Primitive Roots, and Standard Congruences. Pp. 136. (London: F. Hodgson, 1922.)

**Drumaux, P.** L'Évidence de la théorie d'Einstein. Sup. Roy. 8vo. Pp. 72. (Paris: J. Hermann, 1923.) 6 francs.*

**Ferguson, D. F.,** and **Piggott, H. E.** Areas and Volumes: their Accurate and Approximate Determination. Cr. 8vo. Pp. vii+88. (London, Bombay and Sydney: Constable and Co., Ltd., 1923.) 3*s.* 6*d.* net.*

**Fleury, H.** Exposé élémentaire de la théorie d'Einstein. Cr. 8vo. Pp. 34. (Paris: E. Larousse, 1922.)

**Gibbs, R. W. M.** Constructive Arithmetical Exercises. Based on A. E. Layng's Arithmetic. (Extended with Reference Notes.) Part 1. Gl. 8vo. Pp. xi+244+44. (London, Glasgow and Bombay: Blackie and Son, Ltd., 1922.) 3*s.* 6*d.* net.

**Gordon, J. W.** Generalised Linear Perspective: Treated with Special Reference to Photographic Land Surveying and Military Reconnaissance. Demy 8vo. Pp. xvi+184. (London, Bombay and Sydney: Constable and Co., Ltd., 1922.) 21*s.* net.*

**Knopp, K.** Theorie und Anwendung der unendlichen Reihen. (Die Grundlehren der mathematischen Wissenschaften in Einzeldarstellungen, Band 2.) Pp. x+474. (Berlin: J. Springer, 1922.)

**Krichewsky, S.** A Method of Curve Fitting. (Ministry of Public Works, Egypt: Physical Department Paper No. 8.) Imp. 8vo. Pp. iii+17+2 plates. (Cairo: Government Publications Office, 1922.) P.T. 5.*

**Miner, J. R.** Tables of $\sqrt{1-r^2}$ and $1-r^2$ for Use in Partial Correlation and in Trigonometry. Med. 8vo. Pp. 49. (Baltimore: The Johns Hopkins Press, 1922.) 1 dollar.*

**Pompignan, A. de.** Note sur le calcul tensoriel. Sup. Roy. 8vo. Pp. 32. (Paris: J. Hermann, 1923.) 3 francs.*

**Steele, R.,** Edited, with Introduction, by. The Earliest Arithmetics in English. (Published for the Early English Text Society.) Med. 8vo. Pp. xviii+84. (London: Oxford University Press, 1923.) 15*s.* net.

**Study, E.** Mathematik und Physik: eine erkenntnistheoretische Untersuchung. (Sammlung Vieweg, Heft 65.) Demy 8vo. Pp. 31. (Braunschweig: F. Vieweg und Sohn, 1923.) 675 marks.*

**Tuckey, C. O.** Elementary Algebra. Part 1. Cr. 8vo. Pp. 178. (London: E. Arnold and Co., 1923.) 3*s.* 6*d.* net.

**Whipple, G. C.** Vital Statistics: an Introduction to the Science of Demography. Second edition revised and brought up to date. Fcap. 8vo. Pp. 576. (New York: J. Wiley and Sons, Inc., 1923.) 4 dollars.

## Mechanics: Mechanical Engineering

**Beck, E. G.,** Edited by. The Practical Engineer Mechanical Pocket Book and Diary for 1923. 18mo. Pp. 590+cxlix. (London: H. Frowde and Hodder and Stoughton, 1923.) 2*s.* 6*d.* net.

**Bramley-Moore, S.** Motors in a Nutshell: a Plain Description of the Modern Chassis, with Illustration and Diagrams of the Engine, Carburettor, Magneto, and Transmission, together with a section on Roadside Troubles. Fourth edition. Cr. 8vo. Pp. 160. (London: E. and F. N. Spon, Ltd., 1923.) 2*s.* 6*d.* net.

**Cavaillès, H.** La Houille blanche. (Collection Armand Colin.) Fcap. 8vo. (Paris: A. Colin, 1923.) 5 francs.

**Chorlton, A. E. L.** Working Practice in the Design of large Double Acting Two-stroke Engines. Roy. 8vo. Pp. 86. (London: E. and F. N. Spon, Ltd., 1923.) 5*s.* net.

**Crawford, W. J.** Elementary Graphic Statics. (Griffin's Scientific Text-books.) Second edition. Cr. 8vo. Pp. 140. (London: C. Griffin and Co., Ltd., 1923.) 5*s.* net.

**Delaveuve, R.** Notes sur les courroies de transmission. Pp. 72. (Paris et Liége: Ch. Béranger, 1922.) 12 francs.

**Department of Scientific and Industrial Research.** Manchester Association of Engineers: Report of the Lathe Tools Research Committee. Demy 8vo. Pp. 89. (London: H.M. Stationery Office, 1922.) 5*s.* net.*

**Dinwoodie, W.** Wave Power Transmission. Roy. 8vo. Pp. 28. (London: E. and F. N. Spon, Ltd., 1923.) 3*s.* 6*d.* net.

**Fichot, E.** Les Marées et leur utilisation industrielle. (Collection Science et Civilisation.) Large Cr. 8vo. Pp. vi+255. (Paris: Gauthier-Villars et Cie, 1923.) 9 francs.*

**Fowler's** Mechanical Engineer's Pocket Book, 1923. 18mo. Pp. 618. (London: Fowler and Co., 1922.) 3*s.* net.

**Fowler's** Mechanics' and Machinists' Pocket Book, 1923. Edited by W. H. Fowler. Fifteenth annual edition. 18mo. Pp. 515. (London: Fowler and Co., 1922.) 2*s.* net.

**Gray, W. M.** Naval Architecture: a First Course in Ship Calculations. Med. 8vo. Pp. v+201. (London: Methuen and Co., Ltd., 1923.) 12*s.* 6*d.* net.

**Hetzel, F. V.** Belt Conveyors and Belt Elevators. 12mo. Pp. 333. (New York: D. Appleton and Co., 1922.)

**Hill, F. T.** Practical Aeroplane Construction: a Treatise on Modern Workshop Practice as applied to the Building of Aircraft. A Handbook for Students, Apprentices, and Draughtsmen interested in the Aeronautical Industry. New impression. Demy 8vo. Pp. 248. (London: E. and F. N. Spon, Ltd., 1922.) 10*s.* net.

**Johnson, V. E.** Model Aeroplaning: its Practice and Principles. New impression. Demy 8vo. Pp. 265. (London: E. and F. N. Spon, Ltd., 1922.) 6*s.* net.

**Liénard, G.** Construction automobile. Pott 8vo. Pp. lxxx+476. (Paris: Libr. Dunod, 1923.) 9 francs.

**Monvoisin, A.** La Conservation par le froid des denrées périssables. Chimie et microbiologie des substances alimentaires, production du froid, emploi du froid dans la conservation des viandes, des œufs, des produits de laiterie, en sériciculture, en horticulture, en floriculture, en boulangerie et dans les industries des boissons fermentées. Roy. 8vo. Pp. xxii+502. (Paris: Libr. Dunod, 1923.) 52 francs.

**Nasmith, F.,** and **McLachlan, J.,** Edited by. Calvert's Mechanics' Almanack for 1923. Fcap. 8vo. Pp. 197. (Manchester and London: J. Heywood, Ltd., 1923.) 6*d.* net.

**National Research Council.** Highway Research Projects in the United States: Results of Census by Advisory Board on Highway Research, Division of Engineering, National Research Council, in Co-operation with the Bureau of Public Roads, United States Department of Agriculture. By W. K. Hatt. (Bulletin, Vol. 4, Part 3, No. 21.) Sup. Roy. 8vo. Pp. ii+103. (Washington: National Academy of Sciences, 1922.) 1.50 dollars.*

**Reveille, J.** Dynamique des solides. (Encyclopédie de mécanique appliquée.) Med. 8vo. Pp. 506. (Paris: J.-B. Baillière et fils, 1923.) 40 francs.*

**Vaillot, G.** Les Moteurs Diesel et les moteurs semi-Diesel: Types fixes et types marines. Théorie, description, combustibles, construction, conduite, avaries entretien. 2 vols. Demy 4to. Vol. 1. Pp. xii+610. Vol. 2. Pp. 374+29 planches. (Paris: Libr. Dunod, 1923.) 180 francs.

## Physics: Electrical Engineering

**Arnold, C.,** Edited by. The Practical Engineer Electrical Pocket Book and Diary for 1923. 18mo. Pp. 636+cxxiii. (London: H. Frowde and Hodder and Stoughton, 1923.) *2s. 6d.* net.

**Bardin, R.** L'Éclairage et le démarrage électrique des automobiles. Cr. 8vo. Pp. 64. (Paris: Libr. Desforges, 1922.) 3 francs.

**Benischke, G.** Die Transformatoren. Zweite Auflage. Pp. viii+277. (Braunschweig: F. Vieweg und Sohn, 1922.) 70 marks.

**Branly, E.** La Télégraphie sans fil. (Collection Payot.) Cr. 8vo. Pp. 166. (Paris: Payot et Cie., 1922) 4 francs.

**Clavier, A.** Les Ondes courtes (émission, réception). Pp. 47. (Paris: Libr. Chiron, 1922.) 4 francs.

**Conseil Permanent International pour l'Exploration de la Mer.** On Measurement of the Penetration of Light into the Sea. (Publications de Circonstance, No. 76.) Sup. Roy. 8vo. Pp. 16. (Copenhague: A. F. Høst et fils, 1922.) *

**Fowler's** Electrical Engineer's Pocket Book, 1923. 18mo. Pp. 562. (London: Fowler and Co., 1922.) 3*s.* net.

**Fuchs, F.** Elektrische Strahlen und ihre Anwendung (Röntgentechnik). (Der Werdegang der Entdeckungen und Erfindungen, Heft 3.) Pp. 35. (München und Berlin: R. Oldenbourg, 1922.)

**Goldsmith, J. N., Lewis, S. J.,** and **Twyman, F.** Optical Methods in Control and Research Laboratories. Vol. 1: Spectrum Analysis, Absorption Spectra, Refractometry, Polarimetry. Second edition. Roy. 8vo. Pp. iv+56+3 plates. (London: Adam Hilger, Ltd., 75a Camden Road, 1923.) *1s. 6d.** 

**Institut International de Physique Solvay.** Atomes et électrons. Rapports et discussions du Conseil de Physique tenu à Bruxelles du 1er au 6 avril 1921 sous les auspices de l'Institut International de Physique Solvay. Roy. 8vo. Pp. vii+272. (Paris: Gauthier-Villars et Cie., 1923.) 20 francs.*

**Johnson, J. H.,** Edited by. The Electrical Engineer's Year-Book and Diary. Imp. 8vo. Pp. 498. (London: S. Davis and Co., 1923.) *21s.*

**Klingenberg, G.** Large Electric Power Stations. Vol. 3: A 130,000 Kilowatt Power Station. Translated by O. Feldmann. Roy. 8vo. Pp. 154+4 plates. (London: C. Lockwood and Son, 1923.) *21s.* net.

**König, A.** Die Fernrohre und Entfernungsmesser. (Naturwissenschaftliche Monographien und Lehrbücher, Band 5.) Roy. 8vo. Pp. vii+207. (Berlin: J. Springer, 1923.) *7s. 6d.**

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**Department of the Interior: Bureau of Education.** Supervision of Rural Schools. By Katherine M. Cook. (Bulletin No. 10.) Med. 8vo. Pp. iii+111. (Washington: Government Printing Office, 1922.) 15 cents.*

**Jordan, D. S.** The Days of a Man: being Memories of a Naturalist, Teacher, and Minor Prophet of Democracy. In 2 vols. Med. 8vo. Vol. 1, 1851–1899. Pp. xxix+710+56 plates. Vol. 2, 1900–1921. Pp. xxix+906+56 plates. (Yonkers-on-Hudson, N.Y.: World Book Co., 1922.) 15 dollars.*

**Oesterreich, T. K.** Occultism and Modern Science. Translated from the second German edition. Cr. 8vo. Pp. vii+181. (London: Methuen and Co., Ltd., 1923.) 6*s.* net.*

**Royal Society of London.** Year-book of the Royal Society of London, 1923. (No. 27.) Demy 8vo. Pp. iv+202. (London: Harrison and Sons, Ltd., 1923.) 7*s.* 6*d.**

**Science Masters' Association.** Elementary Science, Nature Study, and Practical Work in Preparatory Schools and the Lower Forms of Secondary Schools: being a Report of the Sub-Committee appointed by the Science Masters' Association, 1922. Demy 8vo. Pp. 20. (London: Oxford University Press, 1923.) 1*s.* net.*

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**Cunha, P. J. da.** Reflexões sôbre a teoria dos conjuntos. 8vo. Pp. 64. (Lisboa: Imprensa Nacional, 1922.)

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**Fontené, G.** La Relativité restreinte. Avec un appendice sur la relativité généralisée. Gl. 8vo. Pp. 116. (Paris: Libr. Vuibert, 1923.) 6 francs.

**Geiringer, H.** Die Gedankenwelt der Mathematik. 8vo. Pp. 200. (Berlin und Frankfurt a. M.: Verlag der Arbeitsgemeinschaft, 1922.) 35 marks.

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**Institute of Marine Engineers.** Internal Combustion Engines: Papers Read and Discussed at the Premises of Marine Engineers, 85-88 The Minories, Tower Hill, E.1, December 1922. Demy 8vo. Pp. 600. (London: Institute of Marine Engineers, 1923.) 12*s.* 6*d.* net.

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**Graetz, L.,** Herausgegeben von. Handbuch der Elektrizität und des Magnetismus. Band III, Lieferung 4. Pp. xii+350. G.Z. 16 marks. Band III vollständig: Elektronen und Ionen. Pp. xii+1074. G.Z. 48 marks. (Leipzig: J. A. Barth, 1923.)

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**"Mechanical World"** Electrical Pocket Book, 1923. Fcap. 8vo. Pp. 326+Diary. (London: Emmott and Co., Ltd., 1923.) 1*s*. 6*d*. net.

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**Ricker, C. W.,** and **Tucker, C. E.** Electrical Engineering Laboratory Experiments. Med. 8vo. Pp. xiv+310. (London: McGraw-Hill Publishing Co., Ltd., 1922.) 11*s*. 3*d*.*

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## Chemistry

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**Conant, J. B., Clarke, H. T., Adams, R.,** and **Kamm, O.,** Edited by. Organic Syntheses: an Annual Publication of Satisfactory Methods for the Preparation of Organic Chemicals. Vol. 2. Med. 8vo. Pp. vii+100. (New York: J. Wiley and Sons, Inc.; London: Chapman and Hall, Ltd., 1922.) 7*s*. 6*d*. net.*

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**Mulliken, S. P.** A Method for the Identification of Pure Organic Compounds by a Systematic Analytical Procedure based on Physical Properties and Chemical Reactions. Vol. 4: Containing Classified Descriptions of about 3700 of the more Important Compounds belonging to Fourteen of the Higher Orders. Sup. Roy. 8vo. Pp. vii+238. (New York: J. Wiley and Sons, Inc.; London: Chapman and Hall, Ltd., 1922.) 30*s*. net.*

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# The Water in the Atmosphere.[1]

By Dr. G. C. Simpson, F.R.S., Director of the Meteorological Office.

THE dictionary definition of "saturation" is "the state of a body when quite filled with another," and it is usual to think of saturated air as air which is full of water vapour to such an extent that further water cannot be added without condensation taking place. This, however, is a wrong conception, for there is no limit to the amount of water vapour which air can contain at any temperature, provided that it is perfectly pure, except that ultimately the molecules of vapour will be so near together that there will be no distinction between vapour and liquid.

Air at 30° C. is said to be saturated when its vapour pressure is 31·51 mm. of mercury, but if to such saturated air we add water in sufficiently small drops it will be evaporated immediately and the liquid drops transformed into invisible vapour. If we could add drops with so small a diameter as $1{\cdot}6 \times 10^{-7}$ cm. the air would devour them with avidity until its vapour pressure was more than 126 mm., and then would be ready for more if smaller drops could be supplied.

The question of whether air can hold more vapour or not depends entirely on how the water is presented to it. If the water is presented with a flat surface, evaporation will take place until there is so much water vapour present in the air that as many water molecules return to the surface as leave it; the air is then saturated with reference to a flat surface of pure water. If the surface is curved—convex towards the air—more water molecules will leave each square centimetre of the surface than in the case of a flat surface; hence there must be more vapour molecules in the air before equilibrium is attained. Thus the saturation vapour pressure over a curved surface is higher than over a flat surface at the same temperature. On the other hand, if the water contains certain impurities—*e.g.* sulphuric acid, calcium chloride, and salts in general—less molecules leave the surface than in the case of pure water; hence a smaller number of molecules in the air will be sufficient to produce equilibrium over a solution.

In accordance with the usual practice we will describe air as saturated when the water vapour it contains is in equilibrium with a flat surface of pure water at the same temperature. This will define the saturation pressure at each temperature, and relative humidities will be given in terms of this saturation pressure.

It is well known that water can exist in the liquid state at temperatures far below the freezing point, and therefore water and ice may exist side by side over a large range of temperature. But the vapour pressure which is in equilibrium with ice at a given temperature is lower than that which is in equilibrium with supercooled water at the same temperature; that is, air is in equilibrium with ice at a relative humidity below 100 per cent.

Thus, according to our definition of relative humidity, the water vapour in air may be in equilibrium with water over a large range of relative humidities according to the physical state of the water present. The following tables give the relative humidity of air in equilibrium with pure water in the liquid and solid state.

Table I.

*Relative humidity of air in equilibrium with water surfaces of various radii at 0° C.*

| Radius, cm. | Flat. | $1{\cdot}0 \times 10^{-3}$. | $1{\cdot}1 \times 10^{-5}$. | $2{\cdot}5 \times 10^{-6}$. | $7{\cdot}2 \times 10^{-7}$. | $1{\cdot}6 \times 10^{-7}$. |
|---|---|---|---|---|---|---|
| Relative humidity | 100 | 100·00012 | 101 | 105 | 120 | 400 |

Table II.

*Relative humidity of air in equilibrium with a flat surface of ice at various temperatures.*

| Temperature | 0° C. | −10° C. | −20° C. | −30° C. | −40° C. | −50° C. | −60° C. |
|---|---|---|---|---|---|---|---|
| Relative humidity | 100 | 91 | 82 | 74 | 67 | 61 | 55 |

## Condensation at Temperatures above the Freezing Point.

It was in 1880 that Aitken first showed that condensation does not necessarily take place in air when its temperature is lowered below the dew point. He expanded carefully filtered air and found that no fog formed even when there was considerable supersaturation. Aitken was led to the conclusion "that vapour molecules in the atmosphere do not combine with each other, that before condensation can take place there must be some solid or liquid nucleus on which the vapour molecules can combine, and that the dust in the atmosphere forms the nuclei on which the water-vapour molecules condense."

Aitken invented a most ingenious instrument, easy to work and very transportable, by means of which it is possible to count the number of nuclei present in the air. Thousands of tests of the atmospheric nuclei have been made with this instrument at many places over the world, and nowhere has air free from nuclei been found. The number of nuclei is seldom less than 100 per c.c., while in most country places the nuclei rise to thousands, and in cities such as London and Paris the number may be so great as 100,000 to 150,000 per c.c.

The general explanation of these observations is as

[1] Discourse delivered at the Royal Institution on Friday, March 2, 1923.

follows. If there were no dust particles present the drops of water would have to be built up from aggregates of water molecules. Now the radius of a water molecule is $2 \times 10^{-8}$ cm., therefore if a few molecules met together by chance they would only form a very small drop, which would be so small that it could not exist unless there was large supersaturation. For example, according to Table II. a drop having a radius of $7{\cdot}2 \times 10^{-7}$ cm. would require a supersaturation of 20 per cent., yet nearly 20,000 water molecules would be required to form such a drop. If, however, there were dust particles present the molecules of water would be deposited on them, and the radii of the initial drops would be so large that little supersaturation would be required to maintain them.

This explanation appeared to satisfy every one for a long time, but in recent years considerable doubt has begun to be expressed. Already, in 1885, Assmann had searched for the dust nuclei when cloud particles evaporated under the microscope, and had come to the conclusion that if any were present they must have a smaller radius than $2{\cdot}5 \times 10^{-5}$ cm.

In 1912, Wigand made the reverse experiment. He first took careful counts of the number of nuclei in the air, then he created large quantities of dust by beating carpets, blowing up large clouds of coal, coke, and ordinary dust by means of bellows. Although he made such large clouds of dust that it was extremely unpleasant to work in them, he could not find any increase in the number of nuclei in his condensation apparatus.

In 1910, A. Wegener directed attention to another difficulty. The distance one can see through the atmosphere depends on the number of dust particles present and their size. From measurements made at Ben Nevis it had been found, from a comparison between the transparency of the atmosphere and the number of nuclei measured in Aitken's instrument, that the damper the air the less the number of nuclei necessary in order to see the same distance. The observations gave the following result:

TABLE III.

| Depression of the Wet Bulb. | Number of Nuclei present in 1 c.c. with a Constant Distance of Vision. |
|---|---|
| 1·1-2·2° C. | $1{\cdot}25 \times 10^4$ |
| 2·2-3·9 | 1·71 |
| 3·9-5·5 | 2·26 |

This can only be explained if the size of the dust particles increases as the humidity increases, even when the humidity is still far below its saturation value. But this is not an effect which one would expect if the only function of the dust particles is to act as nuclei, for there would be no condensation on them until the air has reached its saturation point. At all humidities less than 100 per cent. the dust particles would remain dry and therefore of constant size.

From these and other observations meteorologists have been led to the opinion that condensation does not commence on dust particles, if dust is to be understood in the ordinary way, but on hygroscopic substances, and that Aitken's instrument does not measure the number of dust particles present but the number of hygroscopic particles.

A great deal of work has recently been done on this question, especially by Köhler in Norway. Working on a mountain in the extreme north of Norway, Köhler analysed the water obtained from the large deposits of rime which formed on the surroundings of his observatory. Rime is frozen cloud particles, and in this way he was able to determine the chemical contents of the actual cloud particles before they had had time to become contaminated. He found that calcium chloride was always present, and concluded that sea-salt obtained from the spray of the sea forms the true nuclei of cloud condensation. His results indicate that when the drops are extremely small there is sufficient salt present to reduce the vapour pressure to the same extent as the small radius of the drop increases it, thus allowing condensation to take place. Köhler is tempted to generalise his results and to contend that sea-salt is the main foreign substance on which condensation takes place. It is, however, not necessary to go so far as this, for there are many other sources of hygroscopic substances. Lenard and Ramsaner have shown that sunlight—probably only the ultra-violet part—acts on the oxygen, nitrogen, and water vapour of the atmosphere, producing very hygroscopic substances.

Large quantities of material capable of becoming condensation nuclei are produced by all processes of combustion. Thus the household fires and factory chimneys of centres of industry produce vast quantities of nucleus-forming material, chief of which is sulphurous oxide, $SO_2$. This, when illuminated by sunlight in the atmosphere, is a very hygroscopic substance capable of causing condensation in unsaturated air. It is estimated that in England something like 5000 tons of sulphur are burnt each day in coal fires, giving enough sulphur products to pollute the atmosphere from Land's End to John o' Groat's. Other products of combustion are also hygroscopic; thus it is not surprising that air from large industrial centres contains enormous quantities of nuclei.

It is not necessary for hygroscopic particles to be large in order for water to be deposited upon them. Their chemical affinity for water is sufficiently large to counterbalance the surface tension forces which cause small pure-water particles to evaporate unless there is

supersaturation. A single molecule of a hygroscopic substance would probably be able to gather around itself sufficient water to make a drop large enough to grow by ordinary condensation. Thus, whereas the hygroscopic properties are important to build up a drop to a certain size, after that size has once been reached the hygroscopic attraction may cease through excessive dilution, but condensation will continue until the drop is in equilibrium with the surrounding vapour.

The ordinary small ion, in my opinion, takes no part whatever in meteorological processes. Before any deposition of water can take place on small ions, four-fold supersaturation is necessary in the case of negative ions and six-fold in the case of positive ions. We have absolutely no evidence of anything like these super-saturations in the atmosphere, and I have shown at some length, in a paper published in the *Philosophical Magazine*, that even in the case of thunder-storms, in which the conditions are by far the most favourable for the formation of supersaturated air, small ions take no part in the condensation. Further, we have no evidence that small ions act like hygroscopic substances; they do not appear to grow appreciably in size in saturated air, in fact they act like any other air molecule until four-fold or six-fold supersaturation is actually reached.

With regard to large ions (Langevin ions), these do appear from Pollock's work to grow with increase of humidity; but, as Pollock found that they do not form in pure air, these ions are probably nothing more than ordinary hygroscopic nuclei, with a small ion attached.

Without detracting in any way from the value of Aitken's work, we see that it is necessary to revise his conclusions, and to say that hygroscopic substances and not dust form the nuclei of condensation. I do not think that Aitken would have been surprised at this development of his work, for he clearly recognised the importance of salt particles as efficient nuclei.

### Condensation at Temperatures below the Freezing Point.

When the temperature of the air is below the freezing point, condensation of the contained water vapour is a still more difficult problem, for there is very little experimental evidence to go upon. One thing is certain: owing to the small amount of vapour present, it is inconceivable that condensation will take place by the fortuitous meeting of molecules; some kind of nuclei therefore will be necessary.

According to experiments made on crystallisation from supersaturated solutions, we may conclude that crystallisation does not start readily on a perfectly spherical surface. An angular nucleus is necessary, and the nearer the angles are to those of the natural angles of the crystal the more readily will condensation take place. When sledging in the Antarctic with Captain Scott in 1911 we became enveloped in a fog during sunshine. On the fog opposite the sun we saw a white bow in the position usually occupied by a rainbow. This phenomenon can only be explained on the assumption that the fog was composed of small spheres; but the temperature was $-29°$ C. ($-21°$ F.). We are quite familiar with super-cooled water drops which have been formed when liquid drops are cooled from temperatures above to temperatures below the freezing point. In this case there was no part of the atmosphere within hundreds of miles of the place of observation in which the temperature was above the freezing point, and almost a dead calm existed at the time; hence these drops could not have formed at a high temperature and then been super-cooled.

The only explanation which appears possible to me is that in the clear air of the Antarctic there are no "dust" particles suitable for condensation available, but there are plenty of the hygroscopic molecules of which we have already spoken. With increasing humidity these hygroscopic molecules attract water from the air and form clusters of water molecules; but we know from colloidal chemistry that such clusters are in the spheroidal and not in the crystalline form. If this explanation is correct we have real liquid drops and the vapour pressure in the air must be that appropriate to a water surface—we may neglect the curvature of the drops, as their radii were probably of the order of 0·001 cm. But according to Table II. air at $-30°$ C. is saturated with reference to ice at a relative humidity of 74 per cent., hence in this case the air was heavily supersaturated with reference to the solid state. This accounts for the fact, recorded at the time, that "the fur of the sleeping-bags and the wool of sweaters became covered with hoar frost," for these substances formed excellent nuclei for the condensation of the water vapour direct into the solid state.

Support for this explanation is given by observations made by Wegener in Greenland. He describes how, in temperatures below $-40°$ C. with perfectly clear air, a strip of fog started at the house and extended for several kilometres in the direction of the wind. At such temperatures condensation takes place on water at 100 per cent. relative humidity, but on ice or solid nuclei at 67 per cent. The actual humidity was between these limits, therefore the air was not saturated with reference to the hygroscopic nuclei, but was supersaturated with reference to solid nuclei. There were, however, none of the latter present in the pure free air, but the air escaping from the hut was highly charged with solid nuclei, chiefly the products of combustion, and when

this contaminated air mixed with the pure air condensation took place and the long strip of mist resulted.

This observation furnishes the explanation of an old-standing difficulty in meteorological optics. Cirrus and other very high clouds frequently exhibit a most beautiful colour effect, which has received the name iridescent clouds, as the clouds appear to be iridescent with colours like those of mother-of-pearl. If cirrus clouds are always composed of ice particles, as one has generally concluded on account of the low temperature of the atmosphere where they form, the colours cannot be satisfactorily explained; but if they are composed of water drops the explanation is easy. If water drops can exist at $-30°$ C. near the earth's surface, there is no longer any reason to postulate ice crystals for the cirrus clouds; and we may now say definitely that iridescent clouds prove that cirrus clouds are sometimes composed of spherical water drops. But it also proves that air, especially in the upper atmosphere, is frequently devoid of solid nuclei on which condensation can take place.

**Haze.**—Perfectly pure air is almost completely transparent to visual light waves, and if the air were always pure we should see distant objects through air almost as clearly as through a vacuum. But the air is never pure; there are always more or less particles of foreign matter present. The action of these particles is twofold: first, they reduce the amount of light reaching the eye from distant objects; and, secondly, in the daytime they scatter the general light of the sky and so send to the eye extraneous light which reduces the contrast between distant light and dark objects on which visibility depends. Generally this foreign matter consists of a mixture of solid ponderable particles and hygroscopic molecules. The latter in perfectly dry air would be practically invisible, but when loaded with water in a humid atmosphere they add to the obscurity of the atmosphere.

The amount of obscurity will therefore vary with the amount of solid matter and with the humidity of the air. Haze is due to this kind of obscurity, and varies in intensity from the slight obscurity of polar regions, which depends almost entirely on the hygroscopic particles, to the dense obscurity of a dust storm in tropical regions, which is due almost entirely to solid particles.

**Mist.**—When the temperature of air falls, the humidity increases until the saturation point is reached. The diameters of the hygroscopic particles grow, but even in saturated air the amount of water extracted is not great, and if there is little solid matter present the obscurity is not marked. But if the temperature falls below the dew point the hygroscopic particles are sufficiently large to form excellent nuclei for condensation, and relatively large amounts of water are deposited for small falls of temperature.

Real condensation has now commenced, and the obscurity changes from that of haze to that of mist. It has been a common practice to record atmospheric obscurity as haze when there is a noticeable difference between the readings of the wet- and dry-bulb thermometers, and as mist when the readings are the same. This, however, is not a true criterion, for the air can be saturated without condensation, while mist cannot be formed until water has been condensed on account of a fall of temperature after the dew point has been reached. The whole process of the formation of haze and mist is continuous, and in practice it is practically impossible to say when haze becomes mist, although extreme cases are easily distinguished. Nevertheless haze and mist are fundamentally different, for haze owes its origin to foreign matter, and the small amount of water associated with hygroscopic nuclei, while mist is due to an actual precipitation of water from vapour to liquid.

**Fog.**—There is, however, no fundamental difference between mist and fog: in most cases fog is only a dense mist, and the density at which mist becomes fog is a matter of definition. It is now the practice of the London Meteorological Office to limit fog to the obscurity in which objects at one kilometre are not visible.

When mist and fog are formed in fairly clear air they are white. On the other hand, if the air contains a large quantity of impurities, such as carbon particles from imperfect combustion, the mist particles absorb the impurities and become themselves dark-coloured. In this way are formed those dense fogs in London which are likened to pea soup. It was originally thought that the density of a London fog was due to the fact that the smoke of the city provided an unusually large number of nuclei on which condensation could take place, thus offering a temptation to the air to deposit its moisture which it could not resist. As a matter of fact, there are always sufficient nuclei in the purest air in England to allow of the formation of fog whenever the meteorological conditions are suitable. The relationship between smoke and fog is peculiar, and may be said to be accidental. The meteorological conditions which are necessary for the formation of fog are such that while they last smoke cannot get away either vertically or horizontally from the place of its origin. Above the fog there is a temperature inversion which effectively prevents all upward motion of either air or smoke, while fogs over the land usually form in calm air. Thus during a fog practically all the smoke which London makes is kept over it and within a few hundred feet of the ground. This smoke, combined with the deposited water, can, as we all know,

produce such an obscurity that midday is as dark as midnight. The total abolition of smoke from London would not reduce the occasions on which mist and fog occur, but many fogs would remain mists, and we should never have a "London particular."

For the formation of mist and fog it is necessary that the temperature of the air should continue to fall after the dew point of the air has been reached. The extent of the fall below the original dew point determines the density of the obscurity, neglecting for the moment the effect of impurities. This cooling can be brought about in several ways, of which only two are of real importance. Fogs may be caused by warm air blowing over a cold sea or a cold land surface, and the method by which the temperature of the air is then reduced on account of turbulence was first explained in a brilliant paper by G. I. Taylor, which has become a meteorological classic. The fogs of London are, however, almost entirely due to the loss of heat from the lower layers of the atmosphere into a clear sky above. The air radiates its heat, its temperature falls, and condensation takes place as already described. Other methods of fog formation, such as the mixing of warm and cold air, are of secondary importance and never give rise to more than patchy local mists or light fogs.

**Clouds.**—Adiabatic cooling plays no part in the formation of mists and fogs, because the pressure changes in any given layer of the atmosphere are relatively small and slow. Appreciable adiabatic cooling can take place only when air is raised in the atmosphere, and then the cooling may be large and rapid.

When air not saturated rises in the atmosphere its temperature is reduced by about 1° C. for every 100 metres of ascent. When the ascent is carried far enough the dew point is reached, after which any further rise will cause condensation on the nuclei present. As the ascent is carried beyond the point of condensation more and more water is deposited, with a consequent increase in the size of the drops. This is the manner in which clouds are formed, and there are very good reasons for saying that it is the only way. Thus there is a fundamental difference between the method of formation of clouds and fogs: fogs form without any ascent of the air, while clouds are never formed without it. Thus it is not correct to describe clouds as fogs of the upper atmosphere.

The very sharp line of demarcation between the air under a cloud and the cloud itself needs explanation. There is no slow transition between the clear air and the cloudy air, as one would expect if clouds were due to the gradual increase in the size of drops from small nuclei to relatively large cloud particles. We must picture the hygroscopic nuclei collecting more and more water around them as they rise with the ascending current, owing to the increase in relative humidity. But when saturation is reached they are still very small, say about $1{\cdot}1 \times 10^{-5}$ cm., that is, they are smaller than the wave lengths of light ($5 \times 10^{-5}$ cm.), and therefore cannot be directly observed, and produce little obscurity in the air, which still appears relatively clear. Drops of this size need supersaturation to grow, but we see from Table I. that only 1 per cent. supersaturation is necessary. They are, however, unstable, for as they grow they need less supersaturation. Thus as soon as the air is sufficiently supersaturated to be in equilibrium with the nuclei the slightest further rise causes the drops to grow very rapidly to the size in which they are in equilibrium with saturated air. The height at which this change occurs is the height of the base of the cloud.

**Rain.**—Before we are able to form a clear idea of the processes which give rise to rainfall it will be necessary to consider the laws of the fall of water drops through the air.

It is well known that in a vacuum all bodies fall at the same rate with a constant acceleration, so that their velocity constantly increases. When, however, bodies fall through a resisting medium, such as air, they more or less quickly reach such a velocity that the resistance of the air equals the pull of gravity, after which they fall with a constant velocity, which is different according to the density and shape of the falling bodies.

Experiments have been made to determine the rate of fall of water drops through air at atmospheric pressure, and the following "end velocities" have been found.

TABLE IV.

| Radius, cm. | Velocity calculated by Stokes, cm./sec. | Velocity observed by Schmidt, cm./sec. | Velocity observed by Lenard, cm./sec. |
|---|---|---|---|
| 0·0005 | 0·3 | .. | .. |
| 0·001 | 1·3 | .. | .. |
| 0·005 | 32 | .. | .. |
| 0·010 | 126 | .. | .. |
| 0·020 | .. | 180 | .. |
| 0·030 | .. | 270 | .. |
| 0·040 | .. | 340 | .. |
| 0·050 | .. | 393 | 440 |
| 0·100 | .. | 577 | 590 |
| 0·150 | .. | 692 | 690 |
| 0·175 | .. | 740 | 737 |
| 0·225 | .. | .. | 805 |
| 0·273 | .. | .. | 798 |
| 0·318 | .. | .. | 780 |

Three important points are to be noticed about these results.

(*a*) The extremely small velocities with which small drops fall. The average radius of the drops in clouds from which rain is not falling is approximately 0·001 cm. Such particles, according to our table, would fall only at the rate of a little over a centimetre a second.

(*b*) As the drops get larger the rate of fall tends to a constant value of about 8 metres a second.

(*c*) Drops for which $r = 0{\cdot}25$ cm. have the most rapid fall, larger drops fall more slowly.

Lenard has given the reason for (*c*). He showed that the friction on the air causes deformation of the drops, so that instead of retaining the shape of spheres they become flattened out, thus presenting an increased resistance to the air through which they are falling. This deformation becomes appreciable when the radius of a drop is about 0·2 cm. and then increases rapidly as the drop grows larger. When the radius is about 0·25 cm. and the drop is falling at the rate of 8 metres a second, any further increase in volume produces a greater flattening, and instead of the velocity being increased it is slightly decreased. When the size of the drop is such that if it were not flattened it would have a diameter of about half a centimetre, $r = 0{\cdot}25$ cm., the drop becomes very unstable, and all drops larger than this quickly break up into a number of smaller drops, which of course fall more slowly. This means that raindrops can never fall through air at a greater velocity than 8 metres a second. Small drops fall slower than this, and large drops flatten out as soon as they are falling at 8 metres a second, and then soon break up into smaller drops.

In the above all the velocities have been given for air at normal pressure. If, however, the pressure is less, all the results are the same, except that the velocities must be increased in the proportion $\sqrt{B}/\sqrt{P}$, in which B is the normal pressure and P the actual pressure.

Dines has found that in Europe the quantity of vapour in air is always very small. If the whole water vapour in the atmosphere on an average summer day were precipitated it would only give a total rainfall of 0·80 in. The greatest amount ever measured on a summer day in Europe would only give 1·5 in. of rain, and of course the quantity is much less in winter. How then can we have rainfall of several inches of rain in the course of an hour or so? The answer is simple: the ascending currents which are necessary to cause precipitation carry with them their own water vapour to supply the rainfall. An ascending current of air which is saturated at 10° C. (50° F.) needs only an upward velocity of 1 metre a second to carry with it sufficient vapour to give a rainfall of more than 1 inch per hour, so that there is no difficulty in explaining the greatest rate of rainfall ever experienced in the tropics.

There are many ways in which the air is caused to rise in the atmosphere; ascending currents up to many metres a second are possible, and do occur in the atmosphere. Let us think of air rising at about 10 cm. per second, which is the order of the upward velocity of the air in depressions. At a certain height cloud particles form as already described. These have a radius of about 0·001 cm. and fall relatively to the air at 1·3 cm. per sec., hence they are carried upwards with the air, but the base of the cloud remains at the same height because new cloud particles are constantly being formed at that height. As the air rises the cloud particles grow in size, because water is being condensed on them, and they lag more and more behind the air. Drops with a radius of 0·002 cm. are falling as rapidly as the air is rising, and therefore remain stationary, while drops of 0·007 cm. are falling at the rate of one metre a second, and therefore fall through the rising air and appear at the earth's surface as rain. It is obvious that this process will continue as long as the ascending currents continue, and in this way we get the continuous steady rain with which we are so familiar in this country.

The rate of rainfall will increase as the upward velocity of the ascending air increases until the upward velocity becomes greater than 8 metres a second. When this occurs no water can fall through the ascending air for the reason already explained. All water condensed in such an upward current—and it will be a very large amount—is carried upwards until the upward air velocity falls below 8 metres a second, as it is bound to do at some height owing to lateral spreading out. Here water accumulates in large amounts. It is the sudden cessation of the upward velocity in such an ascending current which gives rise to the so-called cloud-bursts, for when the sustaining current stops the accumulated water falls just as though the cloud had literally burst.

The accumulated water while it is suspended in the air is constantly going through the process of coalescing into large drops, which at once become deformed and broken up again into small drops. Every time a drop breaks there is a separation of electricity, and this is probably the chief source of electricity in a thunderstorm. This explains why thunder-storms are associated with heavy rainfall and do not occur in polar regions where there is no rain.

**Hail.**—I have already explained how the small liquid cloud particles are carried upwards with the ascending air, but as the air rises its temperature constantly falls, and there must come a point in the ascent when the temperature falls befow the freezing point. The cloud particles do not immediately turn into ice. As a matter of fact it is not an easy matter to freeze perfectly pure water, and water can remain liquid at temperatures far below the freezing point. Observations made on mountains and in balloons and aeroplanes have proved conclusively that cloud particles remain liquid at temperatures so low as −20° C. How far small drops can be super-cooled before they solidify we do not know, but super-cooled drops are in a very unstable state. From Table II. we see that at −20° C.

ice forms when the relative humidity over water is 82 per cent., which means that if water and ice are simultaneously present the relative humidity of the air relative to the ice is 121 per cent., *i.e.* it is 21 per cent. supersaturated. Thus if a few drops become converted into ice they are in a highly supersaturated atmosphere, and so will grow rapidly at the expense of the water drops. Meteorologists generally consider that $-20°$ C. is about the limit at which large water particles can exist without changing into ice.

Let us consider a region in the atmosphere through which there is an ascending current of air. The air is supposed to have a temperature of 20° C., and a relative humidity of about 50 per cent. at the ground. As the air rises, at first its temperature is reduced by 1° C. for each 100 metres of ascent. Hence by the time it has risen 1000 metres its temperature will have been reduced to 10° C., and it will have reached its dew point. Here the cloud level begins. As it rises still further its temperature continues to decrease, but not so rapidly as before, because the condensation of water vapour releases the latent heat of vaporisation. It reaches 0° C. at a height of 3000 metres. Hence the region between 1000 and 3000 metres contains only drops of water. As the air rises above 3000 metres the temperature falls still lower, but the water particles do not freeze at once, they remain super-cooled. We may assume that at $-20°$ C., which is reached at about 6000 metres, the super-cooled drops solidify and the remaining part of the cloud above this level is composed of snow alone.

There will not be a sharp division between the region of super-cooled water and the region of snow. For a certain distance ice crystals and super-cooled water will be mixed together. Such conditions are very unstable, and from considerations of the vapour pressure alone the ice particles grow rapidly, because the vapour over super-cooled water is highly supersaturated with respect to ice. In addition, the slightest contact between ice and super-cooled water causes the latter to solidify at once. The original ice particle will therefore quickly grow in size and, if the ascending current is not too large, will commence to fall. It has, however, to fall through 3000 metres of super-cooled water drops, and in doing so grows appreciably in size. As each super-cooled water particle strikes the ice it solidifies, and also imprisons a certain amount of air, so that by the time the ice particle reaches the bottom of the super-cooled region it is simply a ball of soft white ice without any sign of regular crystalline structure.

If the descent through the super-cooled region has been fairly rapid the temperature of the ice ball will be considerably below the freezing point when it arrives in the region where the temperature is 0° C., and the cloud particles are not super-cooled. As it continues its way downwards it receives a considerable addition of water: in the first place, by direct deposition, because it is colder than the air; and, secondly, by collision with the water particles. This water covers the surface of the cold ice ball with a uniform layer of liquid which quickly freezes into clear solid ice, with little or no imprisoned air. Finally the ice escapes from the bottom of the cloud, and falls to the ground as a hailstone.

When hailstones are split open to show their internal structure we can nearly always see the inner soft white mass of ice which was collected while the stones were in the super-cooled region, surrounded by a layer of clear transparent ice formed by the freezing of the water deposited when the stone was passing through the non-super-cooled region.

This simple explanation of the formation of a hailstone was not considered satisfactory at first, because it was considered that hailstones produced in this way must necessarily be small. Trabert calculated that if a hailstone started to fall from a height of 2 kilometres, and swept up all the water it met on its way down, its radius would grow only by 2 millimetres. But Trabert left many things out of consideration, as pointed out by Wegener. In the first place, he started his hailstone much too low in the atmosphere; he should have started it from a height nearer 8 kilometres than 2. Secondly, he neglected the effect of the ascending currents. We know that there are violent ascending currents during thunder-storms, in which alone hailstones are formed. The ascending currents may be so violent that even large hailstones will not be able to fall through them, but they are all the time falling rapidly relatively to the air, and therefore sweeping water out of it.

The velocity with which a hailstone falls through still air at atmospheric pressure is

$$v = 1246\sqrt{r} \text{ cm./sec.}$$

If, therefore, the velocity of the ascending current were 10 metres per second, the hailstone could not commence to fall until it had a radius of 0·64 cm. It would then commence to fall very slowly as its size grew larger, but it would all the time be moving relatively to the air at a greater rate than 10 metres a second. Thus the effective height through which it would fall would be very great in comparison with the actual height.

It must also be remembered that with such an ascending current no water could fall in the form of rain; all the water would be retained in the cloud, the water content of which could be very large indeed, thus giving large quantities of water to be swept up by the hailstone. When we also take into account that a hailstone is generally very much colder than the surrounding saturated air, so that the deposition of

moisture on it from the vapour would be large, there is no difficulty in explaining the size of all ordinary hailstones.

It must not be considered, however, that an ascending current is steady. Just as we have gusts and lulls in horizontal winds, so we have increases and decreases in the velocity of ascending currents. Thus a hailstone which has penetrated into the lower part of the cloud might be blown upwards and so go through the whole process again. In this case we should have a layer of white ice deposited around the clear layer, around which again there would be another layer of clear ice. In fact, if a hailstone is held by the ascending currents near to the region where the temperature is 0° C., it might well be carried up and down between the regions where the water is super-cooled and where it is not several times. We should then have several concentric layers of clear and white ice, and a broken stone would have the appearance of an onion. Such cases are not at all uncommon.

For the formation of hailstones two conditions must be fulfilled.

(*a*) The clouds must extend through a great vertical height so that the three regions of water particles, super-cooled particles, and snow are extensive and well developed.

(*b*) There must be violent ascending currents, otherwise the stones would fall too rapidly to grow to a large size.

These conditions are best fulfilled in warm regions, for there violent ascending currents are most easily developed, and the condensation starts at a relatively high temperature, so giving regions of water particles and super-cooled water particles of great depth. These are the reasons why hailstones only occur during the summer in temperate regions, and why the most violent hailstorms and the largest hailstones are found in tropical regions.

**Soft Hail.**—If the temperature at the ground were much lower than in the case just considered, the region between the bottom of the cloud layer and the zero isothermal would be much reduced. It is in this region that the hailstone receives its coat of clear transparent ice. The hailstones which then fall would be relatively small, and consist only of the soft white balls appearing in the centre of the more complete hailstones.

Falls of soft hail of this nature are quite common in the winter in Europe and in the hills of India; there are frequently falls of soft hail during the winter and spring in Simla. The reason is clear, for in Europe the temperature of the ascending current is so low that the freezing point is reached almost at the bottom of the cloud, while in Simla the clouds form over the plains, and Simla itself is so high that the region in which water particles exist is mainly below the station. Thus the hail which falls in Europe during the winter and in the hills of India falls almost immediately out of the region of super-cooled water particles, and therefore has had no opportunity for building up a layer of transparent ice.

The form of these soft hailstones is most instructive. In most cases they are like cones with a hemispherical base. It is clear from this form that as they have fallen through the super-cooled region they have struck the water particles on their under sides. This has caused the bases to grow, and the cone above is really the shape of the stream-lines behind the enlarged base. A stone which has once commenced to have this form will retain it throughout, for the cone acts as a kind of tail and tends to keep the base always at right angles to the relative air motion.

**Snow.**—Snow which forms over an ascending air current in which water particles first form will probably have solidified cloud particles for nuclei. Whatever the nuclei may be, as soon as the initial crystals are formed further condensation takes place exactly as in the precipitation of water, but the vapour condenses directly into the solid state without first going through the liquid state. The crystals of water are hexagonal prisms, and water in the crystalline state in the atmosphere shows all the wonderful shapes that this form of crystallisation can take. Having once started, the crystals may grow either along their central axis, giving rise to long thin prisms, or along their six axes to form hexagonal plates.

Sometimes the growth is uniform, so that the result is a perfect hexagonal plate, at others the growth along the axes is more rapid than in the space between; this gives rise to stars, having a beautiful feathery appearance. The actual crystals vary in size, from minute crystals which can scarcely be seen by the naked eye to plates a quarter of an inch in diameter. In cold regions the crystals are small, because there is little water vapour present from which they can grow. In the Antarctic during the winter, when the temperature was always near or below 0° F., only the smallest crystals were seen, so small that they were almost like dust.

When crystals form at temperatures near the freezing point they grow to their largest size. When the air is full of large crystals frequent collisions take place. The crystals become interlocked and bundles of many separate crystals are formed; these produce the ordinary snowflakes which, on account of their size and weight, fall relatively rapidly. It is to these latter that the term snow should be applied. With this restriction, snow occurs only when the temperature is near the freezing point.

# Recent Scientific and Technical Books.

*Volumes marked with an asterisk have been received at "NATURE" Office.*

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# The Interior of a Star.[1]

By Prof. A. S. Eddington, F.R.S.

On December 13, 1920, the angular diameter of a star was measured for the first time in history with an apparatus devised by Prof. A. A. Michelson. Hitherto every star had appeared as a mere point of light, and no test had been able to differentiate it from a geometrical point. But on that eventful evening a 20-foot interferometer constructed at the Mt. Wilson Observatory was turned on the star Betelgeuse, and the measurement revealed that this star had a disc $\frac{1}{20}$ of a second of arc in diameter—about the size of a halfpenny 50 miles away. The distance of Betelgeuse is known roughly (unfortunately it cannot be found so accurately as the distances of many stars), so that we can convert this apparent size into approximate actual size. Betelgeuse is not less than 200 million miles in diameter. The orbit of the earth could be placed entirely inside it.

The stars are thus not limited to objects of comparatively small bulk like the sun; there are among them individuals truly gigantic in comparison. We can add another step to the astronomical multiplication table—a million earths make one sun; ten million suns make one Betelgeuse. This is a comparison of volume, not of amount of material. It leaves open the question whether, in order to obtain one of these giants, we should take the material of ten million suns rolled into one, or whether we should take the material of the sun and inflate it to ten million times its present size. There is no doubt that the latter answer is nearer the truth. Betelgeuse, I admit, contains more matter than the sun (perhaps 50 times as much); but in the main its vast bulk is due to the diffuseness with which this material is spread out. It is a great balloon of low density, much more tenuous than air, whereas in the sun the material is compressed to a density greater than water.

Whether the star is one of these balloon-like bodies or whether it is dense like the sun depends on the stage of its life at which we catch it. It is natural to think that the stars gradually condense out of diffuse material, so that they become denser and denser as their life-history proceeds. We can now see in the heavens samples of every stage in the development of a star. The majority of those seen with the naked eye are in the early diffuse state; that is not because these young stars are really more numerous, but because their great bulk renders them brighter and more conspicuous. What I shall have to say about the inside of a star refers chiefly to the young diffuse stars—the *giant stars* as they are called. The reason is that we understand much more about the properties of matter when it is in the condition of a perfect gas than when it is condensed; although the difficulties of treating a dense star like the sun are not insuperable, we have naturally made the most progress with the easier problem of giant stars.

[1] Discourse delivered at the Royal Institution on February 23.

## Internal Temperatures.

We only observe the physical conditions at the surface of a star, and at first it might seem impossible to learn anything about the conditions in the interior. Consider, for example, the question of temperature. The nature of the light received from Betelgeuse teaches us that the temperature is 3000° C.—not an extravagantly high temperature judged even by terrestrial standards. But this refers, of course, to the layer near the surface from which the observed light is coming; it is just the marginal temperature of the furnace affording no idea of the terrific heat within. I shall not attempt to explain in detail how we manage to calculate the inside temperatures; but I can perhaps show that there is a clue which can be followed up by appropriate mathematical methods.

Elasticity is a well-known property of a gas, familiar to everybody through its practical application in the pneumatic tyre. What gives the gas its elasticity or expansive force is its heat, that is to say, the energy of motion of its molecules hastening in all directions and continually tending to spread apart. The greater the heat the greater the expansive force. Now at any point inside the star a certain condition of balance must be reached; on one hand we have the weight of all the layers above pressing down and trying to squeeze closer the gas inside; on the other hand we have the elasticity of this inside gas trying to expand and force the upper layers outwards. Since neither one thing nor the other happens and the star remains practically unchanged for hundreds of years, we must conclude that these two tendencies just balance. At each point the elasticity and therefore the heat has to be of the exact amount needed to bear the weight of the layers above. That is the principal clue by which we determine how much heat there must be at various depths inside the star.

The internal temperature depends on the particular star considered, but it is generally from 2 to 20 million degrees at the centre. Do not imagine that this is a degree of heat so vast that ordinary conceptions of temperature have broken down. These temperatures are to be taken quite literally. Temperature is a mode of describing the speed of motion of the ultimate

particles of the matter. In a mass of helium at ordinary temperatures the average speed of the atoms is rather less than 1 mile per second; at 4 million degrees it is 100 miles per second. This is a high speed, but not a speed to feel uncomfortable over. Sir Ernest Rutherford describes atoms of helium moving at the rate of 100,000 miles a second. I cannot vie with him. I usually find that my physical colleagues are rather disappointed with our jog-trot atoms in the stars.

### Material and Ætherial Heat.

We must imagine then a typical giant star as a mass of material with average density about that of air swollen to at least a thousand times the bulk of the sun. The atoms of which it consists are rushing in all directions with speeds up to 100 miles a second, continually colliding and changing their courses. Each atom is being continually pulled inwards by the gravitation of the whole mass, and as continually boosted out again by collision with atoms below. The energy of this atomic motion constitutes a great store of heat contained in the star; but this is only part of the store. The star contains a store of another kind of heat—ætherial heat, or æther-waves like those which bring to us the sun's heat across 90 million miles of vacant space. These waves also are hastening in all directions inside the star. They are encaged by the material, which prevents them leaking into outer space except at a slow rate. An æther-wave making for freedom is caught and absorbed by an atom, flung out in a new direction, and passed from atom to atom; it may thread the maze for hundreds of years until by accident it finds itself at the star's surface, free now to travel through space indefinitely, or until it ultimately reaches some distant world, and perchance entering the eye of an astronomer, makes known to him that a star is shining.

The possession of this double store of heat is a condition which we do not encounter in any of the hot bodies more familiar to us. It is a new phase of matter beyond the reach of laboratory experiment, although happily the theory is so simple that there cannot be much uncertainty as to behaviour. It is true that a red-hot mass of iron contains a little of this ætherial heat in addition to the heat comprised in the motion of its molecules, but it is less than a billionth part of the whole. Only in the giant stars does the ætherial portion rise to importance. A red-hot metal emits ætherial heat, but it keeps no appreciable store; it converts the material heat into this form as it is required for use. The star rejects this hand-to-mouth method; and although it is continually changing elements of heat from one form to the other, it keeps a thousand years' supply always in readiness and emits its radiation by leaking ætherial heat from the store. In older theories this feature was not realised; it was supposed that convection currents must exist continually bringing up hot matter from the interior to replace the surface-matter which had radiated and cooled. Now it is seen that the difficulty is rather in the other direction—how does the star dam back the store of æther-waves so that they do not escape from it faster than we observe? This change of view has necessitated modifications of the older theories of Lane and others, and has on the whole considerably simplified the problem.

In the hot bodies of the laboratory the heat is almost entirely in the material form, the ætherial portion being insignificant. In the giant stars the heat is divided between the two forms in roughly equal amounts. Can we not imagine a third condition in which this time the heat is almost wholly ætherial, the material portion being insignificant? We can imagine it, no doubt; but the interesting, and I believe significant, thing is that we do not find it in Nature.

### Light Pressure.

You have heard of the pressure of light—that light actually has mass and weight and momentum and exerts a minute pressure on any object which obstructs it. A beam of light or æther-waves is like a wind, a very minute wind as a rule; but the intense ætherial energy inside the star makes a strong wind. This wind distends the star. It bears to some extent the weight of the layers overhead, leaving less for the elasticity of the gas to bear. That, of course, has to be taken into account in our calculation of the internal temperatures—making them lower than the older theory supposed. Just as æther and matter share the heat-energy between them, so the ætherial wind and the material elasticity share the burden of supporting the weight of the layers above. We are able to calculate the proportions in which they share it. To a first approximation the same proportion holds throughout nearly the whole interior, and the proportion depends only on the total mass of the star—not on the density or even on the chemical composition of the material. Moreover, in order to make this calculation we do not need any astronomical knowledge; all the constants in the formula have been determined by the physicist in his laboratory. We need to know the average molecular weight of the material, but I shall tell you later how we are able to fix that approximately in spite of not knowing what elements to expect in the star's interior; that happens to be one of the benefits of dealing with very high temperatures.

Let us imagine a physicist on a cloud-bound planet, who has never heard tell of the stars, setting to work

to make these calculations for globes of gas of various dimensions. Let him start with a globe containing 10 grams, then 100 grams, 1000 grams, and so on, so that his *n*th globe contains $10^n$ grams. They mount up in size rather rapidly. No. 1 is about the weight of a letter; No. 5, a man; No. 8, an airship; No. 10, an ocean liner; after that comparisons are difficult to find. The following table gives part of his results:

| No. of Globe. | Ætherial Pressure. | Material Pressure. |
|---|---|---|
| 30 | 0·00000016 | 0·99999984 |
| 31 | 0·000016 | 0·999984 |
| 32 | 0·0016 | 0·9984 |
| 33 | 0·106 | 0·894 |
| 34 | 0·570 | 0·430 |
| 35 | 0·850 | 0·150 |
| 36 | 0·951 | 0·049 |
| 37 | 0·984 | 0·016 |
| 38 | 0·9951 | 0·0049 |
| 39 | 0·9984 | 0·0016 |
| 40 | 0·99951 | 0·00049 |

It is obvious why I omit the rest of the table; it consists of long strings of 0's and 9's. But for the 33rd, 34th, and 35th globes the table becomes interesting; and then lapses back into 9's and 0's again. Regarded as a tussle between æther and matter to control the situation, the contest is too one-sided to be interesting, except just from Nos. 33 to 35, where something more exciting may be expected.

Now let us draw aside the veil of cloud behind which our physicist has been working and let him look up into the skies. He will find there a thousand million globes of gas all of mass between the 33rd and 35th globes. The lightest known star comes just below the 33rd globe; the heaviest known star is just beyond the 35th globe. The vast majority are between Nos. 33 and 34, just where the ætherial pressure begins to be an important factor in the situation.

It is a remarkable fact that the matter of the universe has aggregated primarily into units of nearly constant mass. The stars differ from one another in brightness, density, temperature, etc., very widely; but they all contain, roughly, the same amount of material. With a few exceptions they range from $\frac{1}{2}$ to 5 times the mass of the sun. I think we can no longer be in serious doubt as to the general cause of this, although the details of the explanation may be difficult. Gravitation is the force which condenses matter; it would if unresisted draw more and more matter together, building globes of enormous size. Against this, ætherial pressure is the main disruptive force (doubtless assisted by the centrifugal force of the star's rotation); its function is to prevent the accumulation of large masses. But this resistance, as we see, only begins to be serious when the mass has already nearly reached the 33rd globe; and if indeed it is efficacious, it will stop the accumulation before the 35th globe is reached, because by then it has practically completely ousted its more passive partner (material pressure). We do not need to know exactly how strong the resistance must be in order to prevent the accumulation, because, when once the resistance begins to be appreciable, it increases very rapidly and will very soon reach whatever value is required. All over the universe the masses of the stars bear witness that the gravitational aggregation proceeded just to the point at which the opposing force was called into play and became too strong for it.

### Ascending and Descending Temperature Stages.

It was shown by Homer Lane in 1870 that as a gaseous star contracts its temperature will rise. Betelgeuse is typical of the first stage when the temperature has risen just far enough for the star to be luminous. It will go on contracting and becoming hotter, its light changing from red to yellow and then to white. But evidently this cannot go on indefinitely. When the condensation has proceeded far enough the material will be too dense to follow the laws of a perfect gas. A different law then begins to take control. The rise of temperature becomes less rapid, is checked, and finally the temperature falls. We can calculate that the greatest temperature is reached at a density of about $\frac{1}{4}$ to $\frac{1}{3}$ that of water. The sun is denser than water, so that it has passed the summit and is in the stage of falling temperature. So long as the temperature is rising the brightness of the star scarcely changes. It is becoming hotter, but smaller. Calculation shows that the increased output of light and heat per square metre of surface, and the decreased area of the surface, very nearly counteract one another, so that the total output remains fairly steady. But on the downward path the falling temperature and diminishing surface both reduce the light, which falls off rapidly between the successive stages or types which we recognise. That is entirely in accordance with what is observed to happen.

Taking any level of temperature, a star will pass through it twice, once ascending and once descending. In the main we have been in the habit of classifying stars according to their surface temperature, because it is on this that the spectral characteristics of the light, its colour, and the chemical elements revealed, chiefly depend. But that classification mixes together stars from an early ascending stage and from a later descending stage. For example, a star like Betelgeuse just beginning its career is put in the same class with a dense red star which has run its course and reached its second childhood. They are both red stars of low

temperature, and that was good enough for the early attempts at classification. Sir Norman Lockyer always stoutly maintained the existence of the ascending and descending series; but he was almost alone among spectroscopists in this. He did not actually succeed in separating the ascending and descending stars though sometimes he came very near to the right criterion. We owe to Russell and Hertzsprung the actual separation. They discovered it not by spectroscopy, but by measuring the absolute brightness of stars; the greater brightness of the ascending stars, due to their large bulk, easily distinguishes them from the descending stars, at any rate in the low-temperature groups. At the highest temperatures the two series merge into one another.

The disentangling of the two series, and the recognition of the true sequence of stellar evolution, is probably the most revolutionary and far-reaching of recent discoveries in stellar physics. It began to oust the older view about 1914, and it is worth noticing that the discovery was made from observations coming under the province of the older astronomy and not what is generally called astrophysics. The data were parallaxes, proper motions, double star orbits, etc. The spectroscopists had been misled as to the order of evolution, and it was left to the rival branch of astronomy to show the way; but they were not to be outdone for long. Adams and Kohlschütter have found an easy spectroscopic method for distinguishing the ascending and descending stars. Although our main purpose now is to grope in the interior of a star, perhaps we may emerge at the surface for a moment to consider what is the difference of surface condition of a diffuse and condensed star, respectively, which enables the spectroscope to distinguish between them.

### Surface Conditions.

The state of the outermost layers of a star can, it would seem, be influenced by two factors only, (1) the intensity of the stream of radiant energy crossing through them and (2) the intensity of gravitational attraction holding them to the star. The former is measured by the effective temperature, so that we have the two variable factors, temperature and gravity. The spectrum presumably will vary as the conditions governed by these factors vary. We must not expect to be able to classify the spectra accurately in a single sequence; they can vary in two directions. The ordinary classification depends principally on the temperature factor; we may call this the longitudinal sequence. Adams's new method aims at disentangling the transverse sequence corresponding principally to the gravity factor. We may say that his method is really a way of finding the value of gravity at the surface of a star, although it is not yet possible to put the value into actual numbers. Clearly, gravity will be smaller in the diffuse stage than in the dense stage on account of the greater distance from the centre to the surface.

The effect of lowering gravity is to make the density smaller at corresponding temperature. This introduces an important change in the state of the gas, namely, ionisation. At moderately high temperatures the atoms begin to lose one or more of their most loosely attached electrons, a process called ionisation. Ionisation is facilitated by low density and prevented by high density. The theory of ionisation in stellar atmospheres has been chiefly worked out by M. N. Saha, who has arrived at many interesting results. Here we need only remark that the ionised atoms give rise to different spectra, which have long been distinguished from the spectra of the neutral atoms. The lower density in the atmosphere of diffuse stars should strengthen the "enhanced" lines due to ionised atoms, compared with the "arc" lines due to neutral atoms. The difference in general is not very large, but the atoms of certain elements for which the conditions are most critical, are specially sensitive to the change of density. This is the criterion which Adams and Kohlschütter found empirically, and it distinguishes quite easily the ascending and descending series. To a limited extent it also distinguishes the larger and smaller stars within the same series.

Although the stars begin to shine on reaching a temperature of about 3000° and return to this temperature at the close of their luminous existence, they do not all climb the temperature-ladder to the same height. The more massive stars climb higher than the light stars. We can to some extent calculate the height to which they will go; but I am afraid the figures at present are very uncertain, though there is hope of improving them before long. The sun's surface temperature is now about 5900°; I do not think that it ever went higher than 6600°; it had not sufficient mass to go beyond. Sirius, nearly 2½ times as massive as the sun, has climbed to 11,000°, and at the moment is practically at its maximum, having only just turned downward. Still hotter stars like Rigel are known, and these must be more massive still. At the other end of the scale a star of mass less than 1/7 of the sun would not be able to reach 3000°, and could scarcely be luminous; but in any case such small masses would be formed very seldom, for the reason explained earlier in this lecture. It is a well-known fact that hot stars on the average are more massive than cool stars; we see that this is accounted for by the smaller stars being weeded out as the temperature-standard is raised.

### Atoms and Electrons.

We have hitherto pictured the inside of a star as a hurly-burly of atoms and æther-waves. We must now introduce a third population to join in the dance. There are vast numbers of free electrons—unattached units of negative electricity. More numerous than the atoms, the electrons dash about with a hundred-fold higher velocity—corresponding to their small mass, which is only 1/1850 of a hydrogen atom. These electrons have come out of the atoms, having broken loose at the high temperature here involved. An atom has been compared to a miniature solar system; a composite central nucleus carrying positive charge corresponds to the sun, and round it revolve in circular and elliptic orbits a number of negative electrons at comparatively large distances corresponding to the planets. We know the number of satellite electrons for each element; sodium has 11, iron 26, tin 50, uranium 92. Our own solar system with 8 revolving planets represents an atom of oxygen. The thermodynamical theory due mainly to Nernst permits us to calculate roughly how many of these break loose under given conditions of temperature and density; and in a typical star a large proportion of them must have become free.

This condition solves for us our chief difficulty as to the molecular weight of stellar material. We need to know it in order to perform our calculations as to the state of the star; and at first sight it might seem hopeless to arrive at the molecular weight without knowing the elements which constitute the bulk of the material. But suppose first that the temperature is so high that all the satellite electrons have broken away. An atom of sodium will have separated into 12 particles, namely, 11 electrons and 1 mutilated atom; its atomic weight 23 is divided between 12 independent particles, so that the average weight of each is $23/12 = 1{\cdot}92$. Next take iron: the atomic weight 56 is divided between 27 particles; average 2·07. For tin we have 119 divided by 51; average 2·34. For uranium, 238 divided by 93; average 2·56. It scarcely matters what element we take; the average weight of the ultimate particles (which is what we mean by the molecular weight) is always somewhere about 2. If only the stars were a bit hotter than they actually are, it would make our task very easy. Unfortunately, they are not hot enough to give complete separation, and the actual degree of separation will depend on the temperature of the star, thus introducing a difficult complication. Generally at least half the electrons are detached and the molecular weight must be taken as between 3 and 4. I hope that the theory of this dissociation of electrons will be improved, because at present it is the chief bar to rapid progress with the theory of stellar constitution. It is a great help to know that the molecular weight is between 3 and 4; but we have reached a stage when it is becoming necessary for progress to know it for each star within much closer limits.

### Brightness and Mass.

We pictured a physicist on a cloud-bound planet who was able from laboratory data to predict how large would be the masses into which the material of the universe must aggregate. Let us now set him a harder task. We inform him that we have observed these masses of gas, and, choosing one equal, say, to his 34th sphere, we ask him to predict how brightly it will shine. I have already mentioned that the star keeps practically the same brightness so long as it is a perfect gas ascending in temperature, so it should not be necessary to give the physicist any data except the precise mass. To use the same plan as before, we imagine a series of lamps of 10 candle-power, 100 candle-power, 1000, and so on; and his task is to pick out which lamp in this series corresponds approximately to the star. I believe that it is now possible for him to perform this task and to pick out (correctly) the 31st lamp. But for this purpose it is not enough that he should know all about the heat stored in the interior of the star; the brightness of the star depends on the rate at which the æther-waves are leaking out, and that introduces a new subject—the obstructive power of the material atoms which dam back the radiant flow.

Another name for this obstructive power is *opacity*. A substance which strongly obstructs the passage of light and heat waves is said to be opaque. The rising temperature towards the centre of the star urges the heat to flow outwards to the lower temperature level; the opacity of the material hinders this flow. The struggle between these two factors decides how much light and heat will flow out. We have calculated the internal temperature-distribution, so that we know all about the first factor; if then we can observe the outward flow which occurs, that should settle the value of the second factor—the opacity. The outward flow is capable of observation because it constitutes the heat and light sent to us by the star.

One of the troubles of astronomy is that our information about the stars is so scattered. We know the mass of one star very accurately, but we do not know its absolute brightness; we know the brightness of another but not its mass; for a third we may have an accurate knowledge of the density but nothing else. For Sirius, Procyon, and $\alpha$ Centauri our knowledge is fairly complete and accurate; but not any of these are

giant stars in the state of a perfect gas, and they are therefore useless for the present discussion. But within the last year we have been fortunate enough to obtain complete and very accurate information for one of the giant stars, Capella. This is another of the benefits which astronomy has derived from Prof. Michelson's interferometer method of observation. The brighter component of Capella (which is a double star) has a mass 4·2 times that of the sun and a luminosity 160 times greater. We can use these facts to calculate the opacity of Capella in the way I have described; it turns out to be 150 in C.G.S. units. To illustrate the meaning of this, let us enter Capella and find a region where the density is that of the terrestrial atmosphere we are accustomed to; a slab of this gas only 6 inches thick would form an almost opaque screen. Only $\frac{1}{20}$ of the radiant energy falling on one side would get through to the other, the rest being absorbed by the gas.

### Absorption of X-rays in Stars.

It seems at first surprising that 6 inches of gas could stop the æther-waves so effectively; but we might have anticipated something like this from general physical knowledge. We give different names to æther-waves according to their wave-length. The longest are the Hertzian waves used in wireless telegraphy; then come the invisible heat-waves; then light-waves; then photographic or ultra-violet waves. Beyond these we have X-rays, and finally—the shortest of all—the γ-rays which are emitted by radioactive substances.

Where in this series are we to place the æther-waves in the interior of a star? It is solely a question of temperature, and the æther-waves at stellar temperatures are those which we call X-rays—more precisely, they are very "soft" X-rays. Now X-rays, and soft X-rays especially, are strongly absorbed by all substances. The opacity which we have found in Capella is of the same order of magnitude as the opacity of terrestrial substances to X-rays measured in the laboratory. The following table shows a few of the laboratory results compared with the astronomical value for Capella:

| Wave-length (Å). | Absorption-coefficient (opacity) in | | | |
|---|---|---|---|---|
| | Aluminium. | Iron. | Silver. | Capella. |
| 0·5 | 2 | 14 | 10 | ... |
| 0·95 | 11 | 80 | 72 | ... |
| 1·1 | 21 | 125 | 86 | ... |
| 1·3 | 31 | 205 | 152 | ... |
| 2·3 | 136 | ... | ... | ... |
| 10 | ... | ... | ... | 150 |

We have been performing an investigation of the absorption of X-rays in a star, parallel to investigations on the same subject made in the laboratory. In one respect the physicist has a big advantage because he can vary the material experimented on, whereas we have to be content with the material, whatever it is, composing the stars. But, as you see from the table, the physicist is also interested in finding how the absorption changes for different wave-lengths. We can follow him in this, and even do better than him, because he is restricted by certain practical difficulties to a narrow range of wave-length, whereas we can explore a range of wave-length covering a ratio of at least 10 to 1, by using stars of different temperatures. It is true that our results are not yet very accurate; we have only one star, Capella, for which a really good determination is possible, but for other stars rough values can be found. The terrestrial results indicate an extremely rapid change of absorption for slight alterations of wave-length (as is seen from the table); the astronomical results, on the contrary, give a nearly steady absorption-coefficient. We cannot yet detect certainly whether it increases or decreases with wave-length; at any rate there is nothing like the rapid change shown in the foregoing table. This profound discrepancy between astronomical and laboratory results leads us to inquire more deeply into the theory of absorption in a star. It will be found that there is a good reason for it.

We have been taking advantage over our cloud-bound physicist by having a preliminary peep at an actual star. We are not going to allow *him* to do that. He must not use astronomical observations to determine the opacity, but must be able to predict the astronomical value either from pure theory or from terrestrial experiments. This study is of special interest because it plunges us at once among those problems which are most exercising practical physicists at the present time. We started to explore the interior of a star; we shall presently find ourselves in the interior of an atom.

It is now generally agreed that when æther-waves fall on an atom they are not absorbed continuously. The atom lies quiet waiting its chance and then suddenly swallows a whole mouthful at once. The waves are done up in bundles called quanta and the atom has no option but to swallow the whole bundle or leave it alone. Generally the mouthful is too big for the atom's digestion, but the atom does not stop to consider that; it falls a victim to its own greed—in short, it bursts. One of its satellite electrons shoots away at high speed, carrying off the surplus energy which the atom was unable to hold. The bursting could not continue indefinitely unless there were some counter-process of repair. The ejected electrons travel

about, meeting other atoms; after a time a burst atom meets a loose electron under suitable conditions and induces it to stay and heal the breach. The atom is now repaired and ready for another mouthful as soon as it gets the chance.

From this cause a big difference arises between absorption of X-rays in the laboratory and in the stars. In the laboratory the atoms are fed very slowly; the X-ray bundles which they feed on can be produced by us only in small quantities. Long before the atom has the chance of a second bite it is repaired and ready for it. But in the stars the intensity of the X-rays is enormous; the atoms are gorged and cannot take advantage of their abundant chances. The consumption of food by the hungry hunter is limited by his skill in trapping it; the consumption by the prosperous profiteer is limited by the strength of his digestion. Laboratory experiments test the atom's skill in catching food; stellar experiments test how quickly it recovers from a meal and is ready for another. That is why the absorption follows a different law in the two cases.

### Capture of Electrons.

To predict the stellar absorption-coefficient we must accordingly fix attention on the rate of repair of the burst atoms. The atom is wandering about advertising a vacancy for an electron, and numbers of ejected electrons are rushing about on holiday. Many electrons will come up, look at the situation, and go off again. How is the atom to trap the electron into taking up the situation? I will give you the solution of this problem which I am inclined to think fairly probable, though I have not found many who agree with me. We may compare the electron to a stray planet entering the solar system from outside, bearing in mind, however, that the planets (satellite electrons) must be supposed to repel the invader, and the sun (positive nucleus) attracts it. Dynamics teaches us that, provided no actual material collision occurs, the intruder will scarcely ever be captured, but after stirring up things a little will retreat again towards infinity. There are exceptions, as when the sun and Jupiter conspire to capture a comet, but these would be very rare in the conditions corresponding to an atom. In some cases the intruder would turn the tables by carrying off a regular planet, thus compensating for the occasions when it was itself captured. Probably, as regards repair of the atom, as much harm as good would be done on the average.

More delicate persuasion being of no avail, there seems nothing left but for the atom to secure its electron by brute obstruction. For this reason I take the view that usually the capture of an electron occurs through its running against the positive nucleus of the atom. This nucleus has a highly complicated structure, the iron nucleus, for example, consisting of 86 distinct charges arranged in some kind of equilibrium. If by accident an electron runs full tilt into this packed mass, it will agitate it and lose energy in so doing; it will rebound, no doubt, but with smaller velocity insufficient to carry it out of the sphere of attraction of the atom.[3] By a process of exclusion this seems the only method consistent with dynamical laws by which the atom can secure the electron needed for its repair. Therefore I have concluded that the actual electron trap is none other than the positive nucleus—a region at the centre of the atom known to be about $10^{-12}$ cm. in radius. It must be remembered that the nucleus attracts the electrons and will sweep into the trap many which were not initially aimed at it.

This theory has been adversely critised mainly on the ground that it is entirely accordant with the laws of dynamics. At first sight that might not seem a grave objection; but we have got so used to the atom behaving in a way which violates the classical laws, that any theory which does *not* violate them is liable to be viewed with suspicion. While admitting that there are uncertain possibilities in the mysterious region in the interior of an atom, we must note that the present problem belongs to a class of investigations in which the usual dynamical laws are applied by physicists, often with much success. It concerns the motion of a free electron—not yet forming part of any permanent quantised system—a problem which occurs in the theory of conduction of electricity in metals, in thermionic phenomena, and in the scattering of $\alpha$- and $\beta$-particles. In these problems physicists are accustomed to assume (rightly or wrongly) that the classical laws of dynamics are observed, and we have only followed their (good or bad) example. In particular in Rutherford's experiments on scattering, the classical laws of force are found to hold good almost to the boundary of the nucleus itself. There seems to be a fair presumptive evidence that our stellar problem should be attacked in the same way; although we admit that unknown circumstances may intervene.[4]

The strong point in our favour is that this theory

[3] The kinetic energy at the moment of collision with the nucleus is enormously greater than the kinetic energy before entering its sphere of attraction; so that a very small *proportionate* change of kinetic energy by collision would wipe out the original energy of the electron. The imperfect elasticity of the collision is a dynamical consequence of the complex structure of the nucleus. A collision of two simple charges may be perfectly elastic, except that that would apparently prevent a hydrogen nucleus from ever recovering its electron.

[4] While the fast-moving particles undoubtedly penetrate the atom in the way we have assumed, it is held by some that slow-moving electrons (as in the stars) are turned back at the surface. The idea seems to have originated at a time when the positive charge of the atom was thought to be a large sphere coextensive with it; and it seems out of keeping with modern views. It is ignored in current theories of conduction of electricity. Even if it were conceivable that a neutral atom could so ward off an electron, the strongly positive atoms in the stars could scarcely exclude it.

actually does give a value of the absorption-coefficient agreeing with astronomical observation. Thus for Capella the calculated value is 110 as compared with the observed value 150. There are certain doubtful factors which permit of the result being varied by a factor 2 or possibly 3; and we lay no stress on the precise accordance. But it appears to be possible to predict on this hypothesis the brightness of a star of known mass like Capella to within a magnitude, which amply solves the problem proposed to our physicist on the cloudy planet. It may be added that the theory also explains why the absorption in giant stars is nearly independent of the wave-length; but that is a more elementary result which becomes apparent as soon as we realise that the problem is concerned with the rate of repair of the atoms; many alternative theories of the conditions of repair would lead to the same conclusion.

### Source of Stellar Energy.

The store of ætherial heat and the store of material heat in the star may be compared to the accumulators of a power station. We have not yet discovered the dynamos. The accumulators would run down in a few thousand years if they were not replenished. What is the source of the energy maintaining (and during the ascent of temperature increasing) this internal store? We believe now that the source is sub-atomic energy. One theory is that inside the star the simpler elements are gradually being built up into more complex elements, and energy is liberated in the process; a more drastic view is that matter is being entirely annihilated, setting free the whole of its energy of constitution. Taking the first theory, the most conspicuous known case is in the formation of helium from hydrogen. We do not know how to make helium from hydrogen, but we know that it is so made; we know also that 0·8 per cent. of the mass disappears in the process, and this must be the mass of the energy—æther-waves—liberated when the change occurs. Æther-waves weigh very light, and the energy available from this source is colossal. If 5 per cent. of the star consists of hydrogen which turns into helium as a first step in the formation of the higher elements, that would provide energy sufficient for all reasonable demands.

We might perhaps expect that the earliest stars would consist almost entirely of hydrogen, the evolution of the higher elements having little chance of beginning until the interior became hot enough to stimulate the process. But a difficulty arises here. For astronomical reasons it seems impossible to admit that even the earliest stars contain more than a very moderate proportion of hydrogen. I have referred to the fact that our calculations have been practically independent of the chemical constitution of the star; but one reservation ought to have been made—*provided it is not made of hydrogen*. Hydrogen gives results differing widely from all the other 91 elements.

To assume hydrogen as the material would in most cases destroy the general accordance of theory and observation; indeed it is a way of realising the goodness of this general accordance to note how it disappears when hydrogen is substituted instead of a normal element. I think, therefore, that the process of element-building from protons and electrons must have begun before the stellar stage is reached. This is a curious detached piece of knowledge to have come across in exploring the interior of a star—to be able to deny that it is mainly composed of hydrogen though any of the other 91 elements may be present to any extent; and it is still more curious that hydrogen should be the element which we were tempted to build the stars with, so that this apparently random denial hits the mark.

Admixture of hydrogen diminishes the proportion of ætherial energy and ætherial pressure, and so permits gravitation to aggregate larger masses. The occasional formation of stars of exceptionally large mass (20 to 80 times the sun's) may be due to the accidental prevalence of hydrogen in the region where they originated—that is to say, the material was in a more primitive state as regards evolution of the elements.

We need not be greatly concerned as to whether these rude attempts to explore the interior of a star have brought us to anything like the final truth. We have, I think, been able to recognise some of the leading factors participating in the problem and to learn how many varied interests are involved. The partial results already attained correspond well enough with what is observed to encourage us to think we have begun at the right end in disentangling the difficulties, and we do not anywhere come against difficulties which appear likely to be insuperable. The fact is that gaseous matter at very high temperature is the simplest kind of substance for a mathematical physicist to treat. To understand all that is going on in the material of a desk, for example, is a really difficult problem almost beyond the aspirations of present-day science; but it does not seem too sanguine to hope that in a not too distant future we shall be able to understand fully so simple a thing as a star.

## Recent Scientific and Technical Books.

*Volumes marked with an asterisk have been received at "NATURE" Office.*

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**Dickson, L. E.** History of the Theory of Numbers. Sup. Roy. 8vo. Vol. 3: Quadratic and Higher Forms; with a Chapter on the Class Number, by G. H. Cresse. (Publication No. 256.) Pp. v+313. (Washington: Carnegie Institution, 1923.) 3.25 dollars.*

**Farnsworth, P. V.** Industrial Mathematics Practically Applied: an Instruction and Reference Book for Students in Manual Training, Industrial and Technical Schools, for Home Study. Cr. 8vo. Pp. 282. (London: Scott, Greenwood and Son, 1923.) 8*s.* 6*d.* net.

**Gauss, C. F.** Carl Friedrich Gauss' Werke. Zehnten Bandes. Abt. 2. Abhandlungen I und V. Bachmann: Über Gauss' zahlentheoretischen Arbeiten. (Berlin: B. G. Teubner, 1923.) 5*s.* 6*d.*

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**Sommerville, D. M. Y.** Division of Space by Congruent Triangles and Tetraheda. (Proceedings of the Royal Society of Edinburgh, Session 1922–1923, Vol. 43, Part 1, No. 6.) Sup. Roy. 8vo. Pp. 85-116. (Edinburgh: R. Grant and Son; London: Williams and Norgate, 1923.) 2*s.* 8*d.**

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# New Methods of Crystal Analysis and their Bearing on Pure and Applied Science.[1]

By Sir William Bragg, K.B.E., F.R.S.

IT is one of the most fascinating of all studies to trace back the properties of the substances that we see round about us to the manner and the details of their underlying structure. There are in the world, or indeed the universe, a certain number of different kinds of the atoms of which all things are made. We know of rather more than ninety in all. The science of radioactivity has brought to our notice atoms distinguished by special powers of emitting radiations, but the list is not really increased thereby. Everything we see round about us, or are aware of when perhaps we cannot see, is built up by joining together these atoms in various ways: and all the properties of substances, their infinite complications, powers, and beauties, are associated with the properties of the atoms even before construction is begun. It is surely no wonder that we try to find out how this is done.

Chemistry itself has its origin in this quest. One of its early successes was the explanation—incomplete, no doubt—of the part played by oxygen in the act of burning or rusting. As chemistry has grown to its present magnitude all its findings have related to the part played by this or that atom or combination of atoms in determining the properties of various substances. The methods of chemistry are founded on the study of the behaviour of crowds. The smallest portion of any substance handled in the laboratory contains billions of atoms; and the properties of the individual are inferred from the treatment of gross aggregates. The chemist mixes together two liquids in certain proportions, observes, tests, and weighs the results; and he infers that atoms already grouped in certain combinations are ready to change to fresh groupings. From his weighings he finds the proportions in which the atoms break with one another and recombine. He observes and measures their readiness to change partners. Sometimes the exchange is so rapid that energy is liberated with explosive violence. Sometimes it is so slow that it must be hurried, either by the application of warmth or by other means, the quaintest of which is the action of a catalyst, a third body which promotes a new grouping without being finally concerned in it; as the chaperone of bygone days effected the introduction between two people anxious to meet each other and then effaced herself.

The science of radioactivity takes up the study of the atom in a totally different way. It finds that sometimes atoms are endowed with movement so rapid that the individual has enough energy to make its own mark. In the spinthariscope of twenty-five years ago Sir William Crookes showed the separate and visible flashes which were made when a succession of helium atoms, shot out from radium, struck a phosphorescent screen. Each impact made its little flash of light just as when a pebble is dropped at night into a phosphorescent sea. This is a typical experiment belonging to the science of radioactivity, typical in that it deals with the individual and not with the crowd. In this science there is very little concern with the combinations of atoms. It leads more to a study of the nature of the internal structure of the atom: that is why if we wish to understand the atom's inner mechanism we turn to the work which J. J. Thomson, Rutherford, Aston, and others are doing. The new methods with which I deal here attack the question from yet another aspect, based on the recognition of the properties of crystals on one hand and of X-rays on the other.

A crystal that has grown without disturbance presents surfaces of brilliant polish which make with each other angles of characteristic and invariable magnitude. Sometimes one face grows abnormally as compared to others, on account, it may be, of some disposing cause in the circumstances in which the crystal was formed, but in crystals of the same substance the angles between corresponding faces are always exactly the same. There are not, usually, many different kinds of faces on a crystal. Often on careful examination it is found that there are not more than three or four. If we examine specimens of the same crystal which seem at first sight to differ in form, we find that the difference is nothing more than an unequal development of the various types of face. An outward presentment so simple as this must imply a like simplicity in internal design. There must be a unit of pattern which contains but few atoms and, repeated again and again through space, makes up the whole crystal. The idea has long been familiar to the crystallographer, but he could not push the corresponding interpretation to its limits: he had no clue to guide him, no methods of examining the actual details of the design. The reason of the failure is not difficult to understand: the details were too fine to be distinguished under the most powerful microscope. Nor is this a mere question of a lack of technical skill which might be removed at some future time. It will never be possible to see the arrangements of atoms in a crystal.

When we say that we see any particular thing, what we really do is to observe some change which the thing has made in the light waves which reach our eyes after they have been reflected or scattered or in

[1] Sixth Trueman Wood Lecture, delivered at the Royal Society of Arts on January 24.

some other way affected by the thing that is seen. This means that the thing itself must be comparable in size with the wave-length of light. We could not expect to gather from the behaviour of a breaker as it rushed up the beach information as to the size and form of the individual grains of sand over which it had passed. We might expect, however, to be able to gather information as to the extent of a reef from observation of the degree to which it had stilled the waves that traversed it before they reached the shore. Now, the diameter of an atom is quite a thousand times less than the length of the light-waves which affect our eyes. Consequently it is out of the question that we should ever see it in the sense that we can see small objects even under the microscope. A very simple way to realise this point is to consider that the atoms form part of the very lenses of the microscope; and, if we tried to increase our power of microscopic vision by redesigning the optical arrangement, the lenses would have become, so to speak, granular and have lost their optical properties long before we were able to "see atoms by their aid." The fact is that light-waves are adapted for ordinary seeing, and that by the microscope we have stretched their proper range some thousands of times. Nothing that we can ever do with ordinary light will give us the magnification of a hundred million times, which is what we require if we are to study the atoms themselves. We want a new sort of light of immensely finer quality than ordinary light; and we have been fortunate enough to find this in the X-rays. X-rays are simply a form of light the wave-length of which is ten thousand times shorter than that of the light with which we see in the normal way.

There is one more point to be made clear before we can realise how the combination of X-rays and the crystal has opened up a new vista. Although the X-ray is so fine in structure that it can really be affected by the individual atom, the magnitude of that effect is too small to be of any use: it is here that the crystal helps us. We remember that there is in the crystal a perfectly regular repetition of some simple pattern or combination of atoms. When X-rays sweep over them, whatever effect one of the units has, all its fellows have also; and so on the whole there is a combined action big enough in its results to be detected by instruments designed for the purpose. In somewhat the same way, to take an example, each tiny furrow on a piece of mother-of-pearl is of the right order of width to have an effect on the light which is reflected by the whole piece, but the magnitude of one such effect is not enough to make an impression on our eyes. However, on the surface of the pearl there are many thousands of such furrows very like one another and running more or less in the same direction, and what one furrow does the others do also. It is this combined or multiplied action which so affects the light as to give the beautiful play of colour associated with mother-of-pearl.

Now we have all the factors essential to the new methods: the X-rays for fineness of vision and the crystal for combination in the action of the atoms upon the X-rays. It is not necessary now to go into further details; it is only needful to realise that there is an instrument called the X-ray spectrometer in which the reaction between the X-rays and the atomic arrangements enables us to study the form and size and disposition or structure of the atomic patterns of the crystal.

Every crystal is in a way a long avenue down which we can look and see at the far end of it the most primitive groupings of the atoms. The wonder is that we should be able to look so far, that the structure of the crystal should be so finished and so unvarying from first to last that our observation of a crystal big enough to handle should tell us no more and no less than the properties of the one little unit of pattern. If the diamond in a ring were increased to the size of the earth the individual carbon atoms would only be about as big as tennis balls. Yet so faithful is the information which X-rays and crystals give us that we can compare, and indeed measure, the distances from atom to atom with an error less than 1 part in 1000. This new power, which is surely wonderful enough, we naturally apply to the further elucidation of the problem which I described at the beginning. We try to find out, by fresh means, the relations between the properties of substances and the nature of the atomic structures of which they consist.

It might be objected that a crystal is something special and that most bodies do not show the perfect crystalline form. The difficulty is apparent, not real. In the first place, far more substances are crystalline than would be supposed, and actually every substance would more naturally develop into a perfect and characteristic crystal than into any other form. The crystal is the natural condition. Bodies which seem to us to present no crystalline appearance at all are often aggregates of minute crystals jammed together miscellaneously or held like a mush in a semi-liquid matrix. Often, again, as in the case of liquids, the various atoms and molecules have not had time nor peace enough to arrange themselves as they would. Even if many of the substances in the behaviour of which we are most interested, such as iron and steel, are far in form from the perfect crystal, yet we may expect to arrive in the end at an understanding of their structure by the separate examination of the few definite forms of crystal of which, as we know well, the whole mixed mass is compounded.

We may now go on to consider individual cases. It is, perhaps, natural to a new form of inquiry to deal with particular instances of its application as they have been so far made, rather than to attempt broad generalisations. As we consider each case let us look at it from the point of view already emphasised. Let us try to see how the properties of the whole crystal depend strictly upon and are, indeed, an index to the

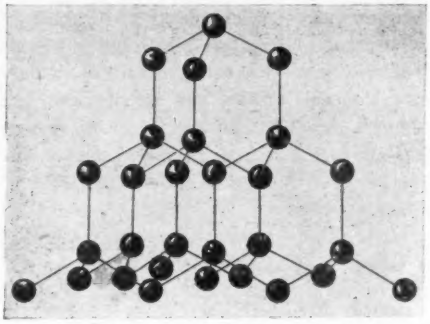

FIG. 1.—Diamond; showing how each carbon atom, represented—only diagrammatically—by a black ball, lies at the centre of gravity of its four nearest neighbours.

properties of the atoms and atomic combinations of which it is made.

The diamond is, perhaps, the best to begin with. Its unique qualities dispose us to expect a structure which is equally distinguished, and so it turns out to be. The structure is figured in the accompanying sketch (Fig. 1). It may look at first sight somewhat complicated, but when it is examined closely it is found that the whole story is told in one sentence. Each atom has four neighbours regularly disposed about it. In other words, the four make a regular tetrahedron, and the first atom is at the centre of it. In the arrangement so determined by X-ray analysis we recognise at once an agreement with one of the most important deductions of the chemist, the so-called tetravalency of the carbon atom, which means a tendency to associate itself with its neighbours by four bonds of equal strength. The hardness and strength of the diamond are based on the simplicity and regularity of this tetrahedron arrangement, and in addition on the strength of the tie between atom and atom. We find that atoms are fastened together by bonds of two or three different types; the one here illustrated is the strongest of all. Every atom, we know nowadays, consists of a central core, which is positively electrified, and of a sufficient number of negative bodies of a second kind called electrons to balance the positive charge on the core. The diamond is an example of many cases where neighbouring atoms share electrons and build them each into their own structure. It is somewhat analogous to the sharing of party-walls by the houses of a terrace. Yet it can be seen that the structure is obviously weaker in certain directions than in others. Such are the horizontal planes in the figure. These are called the cleavage planes. The diamond-worker takes advantage of the fact, using it skilfully instead of grinding. An excellent example is to be found in the exhibit of the Crown Jewels in the Tower, where the manner of cleaving one of the great diamonds is shown. There is a second plane of cleavage, which is only used by workmen of the greatest skill, as it is much more difficult to bring off the operation successfully. It is at right angles to the plane of the first kind. The tetrahedral form of structure is often reproduced in the form of the whole diamond, though no one, I believe, knows exactly why the faces of the tetrahedron are often rounded. This does not mean that the layers of the atoms are curved, but simply that they lie on one another like a series of steps. A structure so tightly bound together is brilliantly clear from the optical point of view.

There is another form of carbon crystal, that of graphite or black lead, the properties of which seem so different from those of the diamond that it is difficult to believe they are of the same element and, moreover, of much the same construction. One common feature is of great interest, namely, the existence in both cases of layers of atoms arranged in hexagonal pattern. It is difficult to express in words, but the illustration (Fig. 2) will make it clear. Each atom is still bound to three

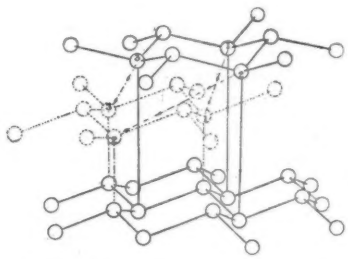

FIG. 2.—The fine lines of the diagram show the structure of graphite. By moving the top layer to the position shown by the broken lines the diamond structure is obtained.

of its neighbours by the same strong ties as before, but the fourth is broken and a weaker, lengthier connexion is substituted. All this is reproduced in the outward appearance of graphite. Its crystals are badly formed, but are more or less in hexagonal columns, which split up with the greatest ease into thin leaves at right angles to the column axis. So easy, indeed, is this cleavage that the pounding of a mass of graphite in a mortar is ludicrously ineffective. The leaves simply multiply themselves more and more. One leaf slides on another very easily, yet the atoms in each leaf hold well together. It is the combination

of these qualities that gives to graphite its lubricating powers. If you slip on the black-leaded hearthstone, it is because some of the layers which are sticking to the sole of your shoe slide on others which cling to the stone. I do not know that you can find a better example of the relation between the external features of a crystal and its elementary structure. One change has converted the hard diamond into the soft, slipping graphite, and it is easy to see that the results are exactly what one would expect from the nature of the change.

Now we may pass on to another structure which is much like that of the diamond, namely, that of ice (Fig. 3). The fundamental element of the design is again the fact that an atom, oxygen in this case, is surrounded symmetrically by four other atoms of like kind; the latter making a regular tetrahedron of which the former is the centre. But there is this difference between diamond and ice: that in the latter case an atom of a second type, namely, hydrogen, is inserted between every pair of oxygen atoms. Thus, the immediate neighbours of each oxygen are four hydrogens. As every hydrogen has only two oxygen atoms as neighbours, there are twice as many hydrogens as oxygens in the structure. That is, of course, in agreement with the known composition of water.

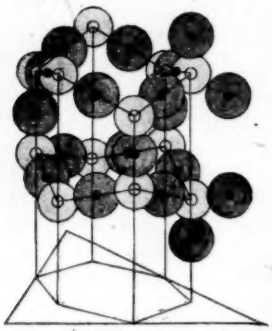

FIG. 3.—Ice. White spheres represent oxygen atoms, and the black spheres hydrogen: enough of each kind are drawn to show the hexagonal nature of the crystal. Each black ball lies between two white: each white touches four blacks, but in two cases only, on the right of the diagram, the full number, four, is put in. The distance between the centres of two neighbouring oxygens is known with accuracy, but it is not known how much of the intervening space is occupied by the hydrogen.

Here, also, as in diamond and graphite, are to be found layers in which the atoms are arranged in a hexagonal pattern. Arctic explorers have described a hexagonal structure in the ice-floes; the block breaking up into hexagonal vertical columns resembling the pillars of the Giant's Causeway. But the most beautiful ice-crystals are found in the snowflakes or in the frost figures on the window. The forms are of an intricate delicacy based always on the hexagon and on the angle of 60°. In the model which is illustrated the foreshadowing of the sixfold symmetry is shown. The featheriness of the snow is the outward expression of the lightness of the pattern, which resembles lace rather than a continuous structure. It is clear that the atoms could be packed more tightly, and that must have something to do with the fact that when ice is compressed it tends to melt. It is not easy to understand why the atoms join together in this of all possible ways. It is evident that particular points in the structure of one atom are linked up with corresponding points in the structure of another. Such considerations have, no doubt, to do with the internal structure of the atoms themselves,

It is a curious fact that when a tetrahedral structure is found, as in the cases of diamond and ice, there is an alternative with respect to one of the details. By a slight structural change somewhat difficult to describe in words, the tetrahedral arrangement of the diamond becomes the usual hexagonal arrangement of ice. Mr. Whipple has directed my attention to a paper written about a hundred years ago, in which the author describes ice-crystals of peculiar form which he had found on the wooden bridge of Queen's College, Cambridge. It is possible to make out from the description that in this case the ice had grown as a diamond would do: the effect is described as one of great beauty and brilliance.

There is one feature of the carbon structures which is of great interest. The hexagonal ring of six atoms is to be found both in diamond and graphite. Now, a whole branch of chemistry of first-rate importance is concerned with the examination of substances of which such a ring forms the essential element of design. When an atom of hydrogen is attached to each atom of carbon the ring with its fringe is the molecule of benzene. The ring is an extraordinarily persistent combination.

Organic chemists have learnt that they can detach at will one or more of the hydrogens, replacing them by somewhat more complicated groups, such as the pair of oxygen and hydrogen atoms called the "hydroxyl group," or the "nitro group," consisting of one nitrogen and two oxygens, and so on. In this way an immense number of different substances are formed of widely varying properties. They occur in the work of the dye chemists, in the manufacture of explosives, in the study of living organisms, and, in fact, constitute a most important class of bodies. Chemists have inferred the existence of these rings by reasoning processes of really wonderful accuracy and power. It is natural to suppose that the ring which we find in our structures is the very ring which has been the concern of the organic chemist.

We have tried to put this idea to the test, and so far, I think, with success. We can measure this ring in the diamond. It is just one hundred millionth of an inch across, and we can make good estimates of the enlargements that must result from such substitutions for the hydrogens as I have already described. We can then measure the space which the rings, modi-

fied or not, occupy in the organic crystal, and we get a very satisfactory fit (Fig. 4).

We have, for example, estimated the size and form of the molecules of naphthalene and anthracene on the assumption that they consist, respectively, of two benzene rings, and three benzene rings, in line; in accordance with chemical evidence. We have found, by X-ray analysis, the size and form of the unit cells (Fig. 6); a simple calculation shows that two molecules have to be packed into the cell in each case; the crystals, it should be observed, are isomorphous.

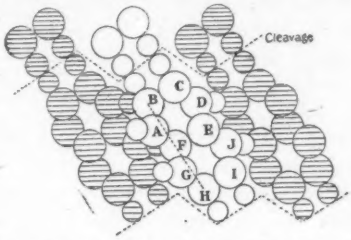


FIG. 4.—Showing mutual relations of three naphthalene molecules and parts of others. Letters are attached to all the carbon atoms of one molecule; hydrogen atoms completing this molecule are attached at A B C D G H I J.

It is found that the molecules pack into place very well, if they are arranged as in the sketch of Fig. 4. The figure refers to naphthalene, but the modification required for anthracene is readily conceived; and, indeed, it appears that the cell in one case is exactly as much longer than in the other as would be expected considering that the anthracene molecule contains one more ring than the naphthalene. Here again we may see in the structure of this little unit of naphthalene, which contains two double rings, everything that foreshadows the properties of the whole crystal. Why is the substance so light? Because the structure is so lace-like and there are so many empty spaces. Why does it break up so easily into thin flakes? Because the molecules lie side by side somewhat like corn bent by the wind, and their side-to-side attachments differ from those that are end to end: the latter break more easily and the substance naturally splits up into layers, each of which is like a velvet pile, the fibres of which represent the molecules. Why does the substance melt so easily? Because *all* the attachments of molecule to molecule are feeble and break up under disturbances due to heat. And so we may go on. If we attach a hydroxyl group to the side of the molecule we see the fibres of the pile open out sideways. If we attach it at the ends, we find the fibres grow longer; the two substances formed in this way are well known in the dye industry.

We have recently been examining the crystalline form of a number of the organic substances, and have learnt something of a very interesting system which governs the packing. It holds for all crystals apparently, but is very plain in the organic field. There are two stages in the process of the formation of the crystal from the original atoms. First of all, the atoms are grouped into companies which the chemist calls "molecules." Chemistry has concerned itself largely with the study of the molecule, and particularly with the molecule in the free state, as in a liquid or a gas. In the second stage the molecules, retaining their composition if not their exact form, are packed together to make the crystal pattern: it is this stage which is the subject of our present considerations, and can be analysed by the X-ray methods. Take a simple example:—Two atoms of hydrogen and one of oxygen make up the water molecule. It is a company of atoms strongly tied together in an alliance which stands much rough treatment. The molecules can exist in a state of independence as steam or water vapour: in a condition of semi-independence they associate themselves together as water. We know how much care has been given to the study of the water molecule in both these states. Now, in the second stage the molecules are arranged side by side and end to end to form the crystal of ice. It has been necessary to take away much of their motion in order to induce them to take the new form. They are no longer running hither and thither, twisting and spinning with the energy of their motion. They lie more quietly now, still quivering, no doubt, but tied together so that they can no longer change appreciably their relative positions. They are now the crystal to be investigated by the new methods: the result is shown in Fig. 3, already described.

We find that when the molecules are packed into the crystal pattern—and they do not seem to suffer much in the process—they are put together just as anyone would try to pack a box with objects all alike in shape but individually of irregular or, one might say, of awkward form. How would you pack a box full of boots? You would naturally put them in pairs, the right boot over the left in the familiar way. It is just such methods of packing that are followed in a crystal. It is convenient to illustrate by means of models. Here are a number of wooden "shoes" which are to represent molecules without symmetry in their form. Take four of them and put them together in the manner illustrated (Fig. 5). The result is a pattern which possesses a certain amount of symmetry,

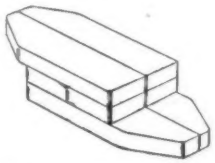

FIG. 5.—Arrangement of the four "shoes" showing the mutual orientation but not the mutual positions of the four molecules usually found in a monoclinic prismatic crystal such as benzoic acid or phthalic acid.

the same, in fact, as that of the boxes in Fig. 6. This is a very convenient form for packing, and it appears that a majority of known crystals pack together in this way. All of them show the symmetry that might

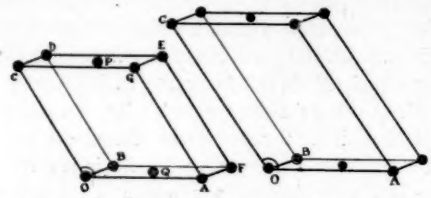


FIG. 6.—Unit cells of naphthalene and anthracene drawn to the same scale ($10^8$ to 1). It is apparently usual for cells of this kind to contain four molecules, but in these two cases they contain two only; that is because the molecules have some symmetry of their own. The molecules shown in Fig. 4 fit into the naphthalene cell. If the unshaded molecules be supposed to be placed with one end at Q, its general lie is parallel to OC. The two shaded molecules of Fig. 4 would then be placed with their ends at B and F. The anthracene molecule is like that of naphthalene except that there are three rings in a line instead of two; the axis OC is correspondingly larger.

be expected. They are exactly alike on either side of a dividing plane: in other words, they are exactly like their reflection in a mirror. They have, too, an "axis of symmetry"; a half turn about the axis brings no apparent change. Fig. 7 is an illustration

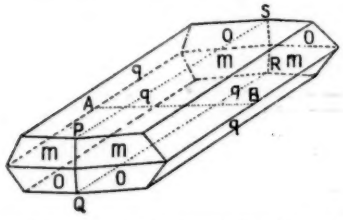


FIG. 7.—Phthalic acid, a monoclinic prismatic crystal possessing a plane of symmetry PQRS, and an axis of digonal symmetry AB, but there is no plane of symmetry through AB. Faces marked by the same letter are alike. The mutual orientation of the four molecules in its unit cell is that of the shoes in Fig. 5.

of a crystal of this kind. The X-ray methods show us that there are four molecules in the unit of pattern, and that they are arranged in the manner described.

It is very interesting to observe the result of a different arrangement. Sometimes a set of four are arranged as in Fig. 8, like two pairs of shoes back

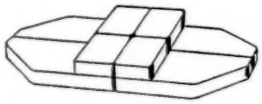

FIG. 8.—The relative orientations but not the relative positions of the four molecules in the crystal unit cell in resorcinol.

to back. The top and bottom are now unlike, but there is a greater symmetry in other directions. We have recently examined a crystal substance, resorcinol, which is built on this pattern; its external form is shown in Fig. 9. The fundamental molecule is a benzene ring in which two hydrogens have been replaced by two hydroxyl (oxygen-hydrogen) groups. The crystal shows clearly different forms at its two ends, the difference of which is shown in another very interesting way. If the crystal is warmed, one end of it becomes positively electrified and the other negatively. We have been able to go some way to the actual determination of the relative positions of the molecules: the results are shown in Fig. 10. There are two sets of planes perpendicular to the axis, which in the crystal occur alternately. In each plane there are two types of molecule, counting difference of orientation as difference of type. The plain lines in the diagram show the arrangement of the two types lying in the plane of the paper, and are marked A and D. One of them can be obtained from the other by a revolution through 180° in the plane. They are joined by long and by short lines, the former containing the oxygens of the hydroxyl groups. The arrangement of the next plane, above or below the first, is shown by the dotted lines: the molecules in this plane can be obtained from those in the first by reflections, with proper translations, across planes that are perpendicu-

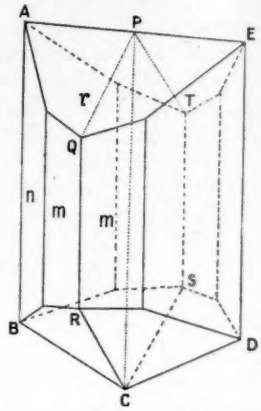


FIG. 9.—Resorcinol, a rhombic pyramidal crystal, having two planes of symmetry, AEDCB and PQRCST, and an axis of digonal symmetry PC.

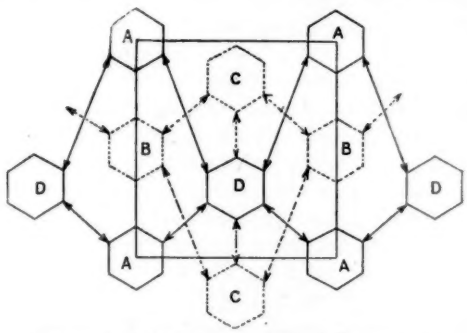


FIG. 10.—Probable arrangement of molecules in resorcinol.

lar to the paper and cut it in lines parallel to either of the sides of the rectangle. The arrangement is clearly governed by the necessity of fitting the molecules together so as to accommodate the hydroxyl attachment.

Another case of great interest and importance is the two-molecule cell, the two being exactly alike. How would you pack a box with boots all right-footed or all left-footed? You cannot find a way of packing

which will make the result symmetrical on either side of a plane. Neither do you find a crystal, built on such a basis, to have right and left symmetry. The crystal of tartaric acid, investigation of the properties of which established the fame of Pasteur, is an excellent

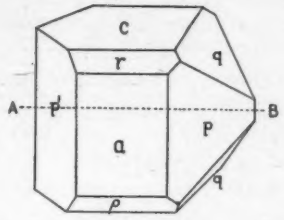


FIG. 11.—Tartaric acid, a monoclinic sphenoidal crystal, having an axis of digonal symmetry, AB, and no other axis or plane of symmetry.

example. Its peculiar form is shown in Fig. 11. A recent publication by Mr. Astbury gives the proof that there are two molecules in the unit cell. Their mode of arrangement in terms of "shoes," which are of one kind only, is shown in Fig. 12. The arrange-

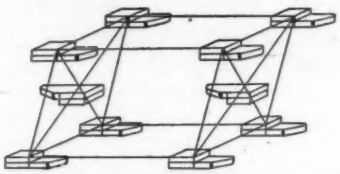

FIG. 12.—Arrangement of "shoes" of one kind only representing the arrangement of molecules in tartaric acid.

ment of the atoms in one molecule, represented in Fig. 12 by one shoe, is shown in Fig. 13. A model of the crystal is shown in Fig. 14; and diagrammatic representations of the atoms in two adjacent molecules are given in Fig. 15 (*a*) and (*b*): one of these figures is right-handed and the other left. The most striking

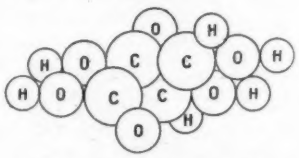

FIG. 13.—Molecule of tartaric acid.

physical property of the crystal is its power of rotating the plane of polarisation of light which traverses it. It has long been guessed that there must be some spiral arrangement in the structure: and this is beautifully confirmed in the model. There are, in fact, two spirals. This is somewhat unexpected, but it explains in a delightful way a property which has been obscure. One of the spirals is in the interior of the molecule itself and is certainly permanent when the crystal is dissolved. That accounts for the fact that tartaric acid in solution is "active," that is to say, can exercise its rotatory power. But the second spiral is a twist brought in by the necessity of fitting

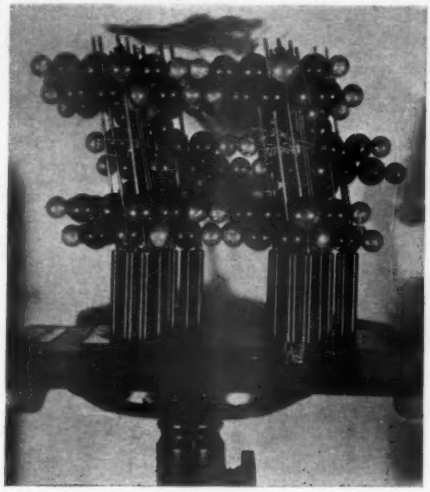

FIG. 14.—Tartaric acid. The small balls represent hydrogen atoms, the larger black balls oxygen, and the largest two grey and two black balls carbon. Scale of the model is $10^8$ to 1.

the molecules in their places. It is a peculiarity of the crystal structure, not of the molecule: it is a right-handed screw if the first is a left-handed screw, and *vice versa*. Also it appears to be more powerful in its effect on the light; so that when the tartaric acid

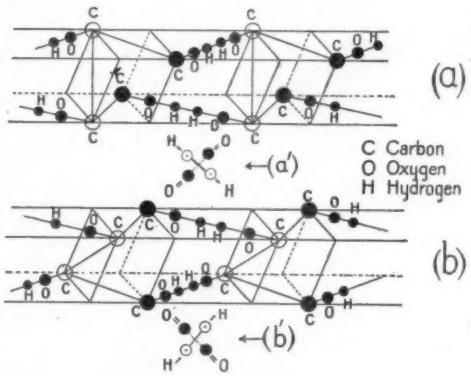


FIG. 15.—Tartaric acid; (a) and (b) represent two molecules end to end; (a') and (b') show corresponding cross-sections with the side attachment. The two sets of figures are right and left to each other.

as a crystal rotates light in one sense, in solution it rotates light in the opposite sense. Here, again, the intricate effects of the whole crystal are directly referred to structural details.

It is to be observed that in this case there could be no question of the existence in the crystal of two molecules related to one another as right to left. For

the mirror reflection of a right-handed screw is a left-handed screw, and the whole effect depends on a want of balance. In this case also there is a plane of cleavage, passing through the points where the molecules join each other end to end.

Quartz is another example of a crystal possessing rotatory power, and like tartaric acid it contains a special element in its construction. The X-ray

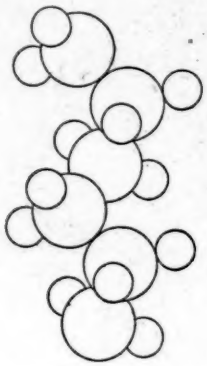

FIG. 16.—Spiral construction in quartz: large balls silicon, small balls oxygen.

methods make this very clear, and give us also some indications as to the structural system. In the model shown in Fig. 16 the large balls represent the atoms of silicon and the smaller those of oxygen. The spiral character of the fundamental crystal is beautifully manifested in its outward form. The illustration (Fig. 17) shows the two possible forms of the crystal,

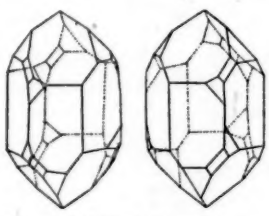

FIG. 17.—Right- and left-handed quartz.

right-handed and left; a certain set of small faces gives to each crystal a spiral appearance.

These various examples have been given as illustrations of the tasks which the new method of crystal analysis undertakes. They belong to a new field of research, akin to chemistry in that they seek to refer the properties of substances to the nature of the elements of construction. Chemistry has, however, concerned itself in the main with the relatively free molecules of liquids and gases: here we deal with the properties of the solid. Our concern is to explain the strength and elasticities of materials, their power of conducting electricity and heat, their electrical properties, optical properties: all these characteristics and many more, in terms of the structure as revealed by the X-ray analysis. Here are, we may say, the contributions of the method to pure science.

It is natural to say something of the possible application to applied science. The properties of solid materials are of such fundamental interest to all arts and crafts that any new insight into their origin is necessarily important. But, at the same time, applications of science to industry are always unexpected in nature and time. What we have now to do from the purely scientific side lies plain before us: how and when any result will have practical value cannot be foreseen.

Much attention has been given to the immensely interesting problems of the crystallisation of iron and steel. Westgren in Sweden, Bain in America, and others, have done good work on the structure of the various forms of iron, $\alpha$, $\beta$, $\gamma$, and $\delta$.

In Great Britain, the effect of the crystalline form on the strength of a material has been examined by G. I. Taylor and Miss Elam in the case of the beautiful aluminium crystals of Prof. Carpenter. The crystals are very easy to deform because certain planes of easy slip traverse the whole crystal, and these planes are always the first to give way. The X-rays show the structure of the crystals and the position of the planes. When the large crystals are broken up into smaller, oriented in all ways, the material becomes stronger because in whatever way a stress is brought to bear some of the crystals are ready to bear it.

Kaolinite, which can be examined, though in the form of a very fine powder, shows clearly a crystalline structure: by the same methods it can be shown that the structure disappears when the temperature is raised to a certain point. These facts were, at least in part, anticipated by the scientific branches of the pottery industry: but this method provides a useful confirmation, and further investigation promises to be very interesting. Calcined at 900° C., a new crystalline structure appears: and when the temperature has been sufficiently raised, the X-rays show that sillimannite has formed.

Such examples are mere pointers in a direction in which we may hope there will be a great movement in time to come. Our first aim is to develop the new methods as pure science. A broad, straight road opens out before us, and the going is good. As we travel along it we shall, doubtless, find many side turnings leading to useful applications, but we must not expect them until we are right opposite to them. Our first and obvious duty is to travel down the high-road as far as it will take us.

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